Chapter 6
Diversity and Spatial Structure

Key Questions:

a) *How have anthropogenic factors such as habitat modification, fishery management, and artificial production programs affected the diversity and spatial structure of steelhead populations?*
b) *What was the distribution of summer and winter steelhead in each region prior to European settlement?*
c) *How has the range of summer and winter steelhead changed from the pre-settlement distribution? What factors caused the change in distribution?*

6.1 Introduction

Diversity and spatial structure are two characteristics of a population that affect population viability (McElhany et al. 2000). We describe and apply methods to evaluate the diversity and spatial structure of extant populations of steelhead in Washington.

> *"…can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and procreating their kind?" "Hence, I look at individual differences, though of small interest to the systematist, as of the highest importance for us…"*
>
> *Charles Darwin, The Origin of Species*

The diversity and spatial distribution of steelhead can be viewed as a hierarchical organization of multiple spatial and temporal scales. The organization can range from the relatively fine scale of habitat patch utilization to the distribution of populations throughout the range of the species. Riddell (1993) schematically represented this relationship using an inverted triangle to illustrate the cumulative contribution of each level of the hierarchy to the diversity of the species. Characteristics of the environment at the lower levels of the hierarchy drive the adaptations of populations and provide the basic unit for the diversity of the species. Two higher levels of this organization, the ESUs and populations of steelhead in Washington, were discussed in Chapter 5, Population Structure. In this chapter we evaluate the status of Washington populations of steelhead at a finer level of the hierarchy - within population diversity and spatial structure.

6.1.1 Diversity

Diversity is the variation among individuals in the expression of a trait. These differences can be the result of genetic differences between individuals, difference in the environment to which they were exposed, or both. Differences in traits that are strictly of genetic origin are often referred to as genotypic differences. Phenotypic differences result from the interaction of genetic and environmental factors.

As Darwin first argued in 1895 in *The Origin of Species*, the variation in individuals is a key condition necessary for natural selection and the evolution of species:

> "Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life, should occur in the course of many successive generations. If such do occur, can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and procreating their kind?" "Hence, I look at individual differences, though of small interest to the systematist, as of the highest importance for us, as being the first steps towards such slight varieties as are barely thought worth recording in works on natural history."

Since Darwin reshaped our concept of the functioning of the natural world, the importance of diversity for the persistence of a species and population viability has become a central tenet of conservation biology. McElhany et al. (2000) identified three general reasons to consider diversity when assessing the viability of a population:

1) Variation in traits allows a species to use a wider array of environments than would be possible in the absence of diversity.
2) Diversity provides the opportunity for some individuals, and the population, to persist when short-term changes occur in the environment.
3) Genetic diversity provides the basis for adaptation to long-term changes in the environment and maintenance of the population.

General guidelines for assuring that the diversity of a population is consistent with viability are provided in Box 6-1.

6.1.2 Spatial Structure

Spatial structure can be related to the viability and production potential of a population. Spatial dispersion provides a hedge against the loss of a population from a catastrophic event or, at a larger scale, the loss of a metapopulation (Ruckelshaus et al. 2003). Catastrophic events include a wide variety of phenomena such as volcanic activity, mud slides, toxic chemical spills, and disease epidemics which can pose a significant risk to population viability (Lande 1993; Mangel and Teir 1994). The hierarchical organization of a salmonid species, Riddell (1993) concluded, implies that maintaining maximum biological diversity, and production potential, necessarily means conserving populations and the habitats on which they depend.

These considerations suggest that an evaluation of spatial structure is important for at least five reasons (see McElhany et al. 2000 for a more detailed review):

Photo 3-1. Dams and other structures can limit the spatial extent of steelhead populations and reduce the viability and production potential of steelhead populations.

- spatial structure affects biological diversity;
- a dispersed spatial structure provides a hedge against the loss of biological diversity from catastrophic events (Ruckelshaus et al. 2003);
- the spatial and temporal distribution, quantity, and quality of habitat (landscape structure) dictates how effectively juvenile and adult salmon can bridge freshwater, estuarine, nearshore and marine habitat patches during their life cycle (Simenstad 2000; Mobrand et al. 1997;
- loss of spatial structure may affect extinction risk in ways not readily apparent from short-term observations of abundance data (Cooper and Mangel 1999); and
- maintenance of spatial structure maintains production potential (Riddell 1993).

General guidelines for assuring that the spatial structure of a population is consistent with viability are provided in Box 6-2.

Box 6-1. Diversity Guidelines

These general guidelines for assuring that the diversity of a population is consistent with viability were provided in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany et al. 2000). Application of the guidelines requires careful consideration of many population and watershed specific factors.

"1. **Human-caused factors such as habitat changes, harvest pressures, artificial propagation, and exotic species introduction should not substantially alter variation in traits such as run timing, age structure, size, fecundity, morphology, behavior, and molecular genetic characteristics.** Many of these traits may be adaptations to local conditions, or they may help protect a population against environmental variation. A mixture of genetic and environmental factors usually causes phenotypic diversity, and this diversity should be maintained even if it cannot be shown to have a genetic basis.

2. **Natural processes of dispersal should be maintained. Human-cased factors should not substantially alter the rate of gene flow among populations.** Human caused inter-ESU stray rates that are expected to produce (inferred) sustained gene flow rates greater than 1% (into a population) should be cause for concern. Human caused intra-ESU stray rates that are expected to produce substantial changes in patterns of gene flow should be avoided.

3. **Natural processes that cause ecological variation should be maintained**. Phenotypic diversity can be maintained by spatial and temporal variation in habitat characteristics. This guideline involves maintaining processes that promote ecological diversity, including natural habitat disturbance regimes and factors that maintain habitat patches of sufficient quality for successful colonization.

4. **Population status evaluations should take uncertainty about requisite levels of diversity into account.** Our understanding of the role diversity plays in Pacific salmonid viability is limited. Historically, salmonid populations were generally self-sustaining, and the historical representation of phenotypic diversity serves as a useful "default" goal in maintaining viable populations."

Box 6-2. Spatial Structure Guidelines
These general guidelines for assuring that the spatial structure of a population is consistent with viability were provided in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany et al. 2000). Application of the guidelines requires careful consideration of many population and watershed specific factors.

“1. **Habitat patches should not be destroyed faster than they are naturally created.** Salmonid habitat is dynamic, with suitable habitat being continually created and destroyed by natural processes. Human activities should not decrease either the total area of habitat OR the number of habitat patches. This guideline is similar to the population growth rate criterion—i.e., a negative trend has deterministically negative affects on viability—though the relationship between decreasing number of patches and extinction risk is not necessarily linear.

2. **Natural rates of straying among subpopulations should not be substantially increased or decreased by human actions.** This guideline means that habitat patches should be close enough together to allow appropriate exchange of spawners and the expansion of the population into underused patches, during times when salmon are abundant (see Guideline 3). Also, stray rates should not be much greater than pristine levels, because increases in stray rates may negatively affect a population’s viability if fish wander into unsuitable habitat or interbreed with genetically unrelated fish.

3. **Some habitat patches should be maintained that appear to be suitable or marginally suitable, but currently contain no fish.** In the dynamics of natural populations, there may be time lags between the appearance of empty but suitable habitat (by whatever process) and the colonization of that habitat. If human activity is allowed to render habitat unsuitable when no fish are present, the population as a whole may not be sustainable over the long term.

4. **Source subpopulations should be maintained.** Some habitat patches are naturally more productive than others. In fact, a few patches may operate as highly productive source subpopulations that support several sink subpopulations that are not self-sustaining. Protecting these source patches should obviously be of the highest priority. However, it should be recognized that spatial processes are dynamic and sources and sinks may exchange roles over time.

5. **Analyses of population spatial processes should take uncertainty into account.** In general, there is less information available on how spatial processes relate to salmonid viability than there is for the other VSP parameters. As a default, historic spatial processes should be preserved because we assume that the historical population structure was sustainable but we do not know whether a novel spatial structure will be.”

6.2 Methods

Prior evaluations of the diversity and spatial structure of salmonids have often been subjective with limited or no explicit linkage to population viability. The WLCTRT (2003), for example, developed a qualitative description of the characteristics of within-population diversity associated with five levels of population persistence (0-40%, 40% -50%, 75 – 95%, 95 - 99%, > 99% over a 100-year time frame), but provided little justification for the risk levels. The WLCTRT (2003) concluded "Clearly we need to know far more that we do now about the spatial structure and fish-habitat relationships to be able to say with confidence that a given spatial structure will support a population over a sustained period of time." Similarly, with respect to within-population diversity, the WLCTRT states "When establishing criteria for within-population diversity, there is considerable uncertainty in defining how much life-history diversity is enough to sustain a population at VSP levels." In the absence of a defined procedure for relating spatial structure and diversity to population viability, we have chosen to simply categorize the extent of changes relative to the historical population (low, moderate, or high).

To evaluate diversity and spatial, we selected three characteristics of populations which seemed likely to be related to viability and for which information was frequently available: 1) genotypic and phenotypic variability; 2) the spatial extent of the population; and 3) an index of spatial structure and connectivity.

6.2.1 Diversity

We evaluated the magnitude of change in the diversity of the population using three metrics: 1) phenotypic characteristics; 2) effective size depression; and 3) and gene flow (Table 6-1). Changes in the phenotypic characteristics of individuals can be the most tangible evidence of loss in the diversity of a population. Our criteria, although similar to the ICTRT (2004), specifically focuses on fitness-related traits of naturally produced steelhead.

Hatchery programs can potentially reduce the effective size of a population if: 1) broodstock for the hatchery program originates from a relatively small part of a composite population of hatchery and natural-origin adults; 2) survival rates of hatchery-origin fish are significantly greater than fish of natural origin; and 3) returning adults from the hatchery program subsequently spawn in the natural environment. We evaluated the potential for a depression in the effective size of a population using the methods of Wang and Ryman (2001) and the criteria in the Benefit-Risk Assessment Program (BRAP) (WDFW 2001).

Gene flow from steelhead that did not originate from the population can reduce the diversity and fitness of a population. Our criteria for gene flow vary depending upon whether the source originated from inside or outside of the GDU of the population. We evaluated gene flow using the criteria in BRAP (WDFW 2001).

Table 6-1. Criteria for categorizing the magnitude of change associated with modifications to the diversity of the population.

Factor	Magnitude of Change		
	Low	Moderate	High
Phenotypic Characteristics	Significant change in mean or variability of < 2 fitness-related traits of naturally produced fish (e.g., migration timing, age structure, size at age).	Loss of 1 trait or significant change in mean or variability of 2 fitness-related traits of naturally produced fish (e.g., migration timing, age structure, size at age).	Loss of > 1 trait and significant change in mean or variability > 2 fitness-related traits of naturally produced fish (e.g., migration timing, age structure, size at age).
Effective Size	Effective size depression low risk to population (Appendix 6-B).	Effective size depression moderate risk to population (Appendix 6-B).	Effective size depression high risk to population (Appendix 6-B).
Gene Flow	Gene flow estimated or inferred: 1) < 1% from populations outside GDU; 2) < 2% from nontarget populations inside GDU.	Gene flow estimated or inferred: 1) 1% from populations outside GDU; 2) 2-4% from nontarget populations inside GDU.	Gene flow estimated or inferred: 1) >1% from populations outside GDU; 2) > 4% from nontarget populations inside GDU.

6.2.2 Spatial Extent of Population

The spatial extent of each population was evaluated in two ways: 1) the presence or absence of spawners in historical spawning areas; and 2) the range of all life history types in freshwater (Table 6-2).

Metrics and general criteria to evaluate the spawning distribution of a population have been suggested by both the WLCTRT (2003) and ICTRT (2004). The WLCTRT relied on a qualitative analysis that evaluated the extent to which historical areas remained accessible. The ICTRT developed a quantitative analysis of spatial data to define major spawning areas (MSA), or a section of a watershed that historically was sufficiently large to support a spawning aggregation of 500 steelhead. We drew upon both of these assessments and applied the qualitative approach to the areas where MSAs had not been defined (Puget Sound, Olympic Peninsula, Washington Coast, and Lower Columbia).

Workshops with fish biologists and Geographic Information System (GIS) analyses were used to identify the distribution of steelhead currently and prior to European settlement ("Pre-Settlement")(see Appendix 6-A for a complete description of methods). Information on the distribution of summer and winter steelhead prior to European settlement (referred to as the "Pre-Settlement" distribution) is limited. During the mapping workshops with biologists, we solicited expert opinion on what the distribution of steelhead would have been in the absence of artificial obstructions or habitat degradation ("Potential Presence"). Not surprisingly, the biologists were often unwilling to include parts of the watershed with which they were not personally familiar. The likely result was that the "Potential Presence" distribution defined a lower limit for the distribution of steelhead prior to European settlement.

We developed an alternative approach to explore this concern and define an upper limit to the distribution of steelhead prior to European settlement. The two-step methodology built on the information collected on the current distribution of steelhead and the spatial modeling capabilities provided by a Geographic Information System (GIS):

> Step 1. Develop a GIS model driven by gradient and current distribution to predict historical the distribution of steelhead.
>
> Step 2. Refine the model predictions through a review process with biologists familiar with the ecological and geomorphic characteristics of each watershed.

We defined the percentage reduction in the range of the population as:

% Loss = (Current Distribution) / (Pre-Settlement Distribution)

Results from the analysis are presented in both a map and summary table format. In the summary tables, the pre-settlement distribution, percent lost, and other statistics are presented by Water Resource Inventory Area (WRIA).[1] The extent of reduction in

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[1] All watersheds within Washington are categorized into one of 62 major watershed basins or WRIAs. The WRIA were formalized under Washington Administrative Code (WAC) 173-500-040 and authorized under the Water Resources Act of 1971, Revised Code of Washington (RCW) 90.54. The original WRIA boundary agreements and judgments were reached jointly by Washington's natural resource agencies Ecology, Department of Natural Resources, and Washington Department of Fish and Wildlife in 1970.

the range was categorized as Low (<%10 reduction), Moderate (10%-30% reduction), or High (>30%) reduction based on the most limiting factor (Table 6-1).

In some watersheds, range extensions have occurred as the result of the introduction of nonindigenous steelhead. These are noted in the text and on the maps, but they are excluded from the summary tables because our primary interest is in determining changes in the spatial structure of the indigenous population.

Table 6-2. Criteria for categorizing the magnitude of change associated with modifications to the spatial extent of the population.

Factor	Magnitude of Change		
	Low	**Moderate**	**High**
Spawning Distribution	1) Absence of spawners from < 10% of MSAs.	1) Absence of spawners from 10%-30% of MSAs.	1) Absence of spawners from > 30% of MSAs.
	2) Absence of spawners from < 10% of pre-settlement spawning areas.	2) Absence of spawners from 10% - 30% of pre-settlement spawning areas.	2) Absence of spawners from > 30% of pre-settlement spawning areas.
Population Range	Pre-settlement range reduced by < 10%.	Pre-settlement range reduced by 10%-30%	Pre-settlement range reduced by > 30%.

6.2.2 Spatial Structure and Connectivity

The spatial structure of the population and connectivity of habitat were evaluated using the Ecosystem Diagnosis and Treatment (EDT) model (Mobrand et al. 1997). In the model, a life history trajectory is defined as the path through time and space of a segment of a population. Trajectories can be initiated at different locations within a watershed, and trajectories that start at the same location can subsequently diverge if a segment of the population spends more or less time in a particular location. A life history trajectory is not sustainable if less than 1 adult is produced for each adult that initiates the trajectory. Reductions in the quality and complexity of channel, floodplain, and estuarine habitat will result in a reduction in the predicted productivity of the habitat. We computed an index of spatial structure and connectivity by comparing the number of trajectories that are currently sustainable with the number that were sustainable prior to European settlement (Table 6-3).

Table 6-3. Criteria for categorizing the magnitude of change associated with modifications to the spatial structure of the population.

Factor	Magnitude of Change		
	Low	Moderate	High
Spatial Structure and Connectivity	Index of spatial structure and connectivity reduced by < 10% relative to pre-settlement value.	Index of spatial structure and connectivity reduced by 10%- 30% relative to pre-settlement value.	Index of spatial structure and connectivity reduced by > 30% relative to pre-settlement value.

6.3 Results

6.3.1 Puget Sound

Our analysis estimates that 8%-26% of the pre-settlement range has been lost for summer steelhead and 3%-21% of the pre-settlement range lost for winter steelhead (Table 6-4)(Figs. 6-1 and 6-2). Significant variation exists among the WRIA in the percentage of the pre-settlement distribution lost. The greatest loss (51%-64%) occurs for summer steelhead in the Dungeness-Elwha WRIA, while relatively small losses are estimated for summer steelhead in the Kitsap (0%-7%) and the Stillaguamish (0%-8%) WRIAs.

Reductions in the range of the distribution have occurred primarily as a result of the construction of impassable barriers such as culverts and dams. Detailed maps of distribution and passage barriers can be obtained through the SalmonScape web site (see Box 5-1), but several of the major barriers at which passage may be provided in the future are identified below:

> Nooksack (WRIA 1). The Bellingham Water Diversion Dam at RM 7.2 blocks access to significant habitat in the Middle Fork Nooksack River. Discussions are underway regarding construction and funding for passage facilities.
>
> Upper Skagit (WRIA 4). Baker Dam blocks access to habitat in the Baker River. A Baker Summer steelhead population may have existed historically, but trap and haul operations currently do not transport summer steelhead.
>
> Green/Duwamish (WRIA 9). Howard Hanson Dam blocks access to the upper Green River. Trap and haul operations have been suspended until smolt passage is provided at the dam, currently targeted for 2008.
>
> Elwha/Dungeness (WRIA 18). The Elwha Dam at RM 4.9 blocks access to the Elwha River. Planning is currently underway to remove both the Elwha Dam and the Glines Canyon Dam.

Range extensions have occurred in four areas as the result of the introduction of non-indigenous steelhead. These are not included in Table 6-4 because the introductions were of nonindigenous steelhead.

> South Fork Stillaguamish Summer Steelhead. Summer steelhead of Skamamia-origin were introduced into the South Fork Stillaguamish River coincident with

the construction of the Granite Falls fish ladder in the mid-1950s. Approximately 121 miles of the watershed are now used by summer steelhead.

South Fork Skykomish Summer Steelhead. Summer steelhead of Skamamia-origin were introduced into the South Fork Skykomish River coincident with the initiation of a trap-and-haul operation at Sunset Falls in the mid-1950s. These introductions appear to have resulted in a self-sustaining population with genetic characteristics that differ from the native North Fork Skykomish populations and summer steelhead of Skamania-origin reared at Reiter Ponds and released into the Snohomish watershed (Kassler and Hawkins, pers. comm.). Approximately 166 miles of the watershed are now used by summer steelhead.

Green River Summer Steelhead. Summer steelhead of Skamania-origin were introduced into the Green River in 1965. Approximately 64 miles of the watershed are now used by summer steelhead.

Deschutes River Winter Steelhead. Winter steelhead of Chambers Creek-origin were introduced into the Deschutes River when a fish ladder was installed at Tumwater Falls in 1954. Approximately 61 miles of the watershed are now used by steelhead, but the production from spawners is unknown.

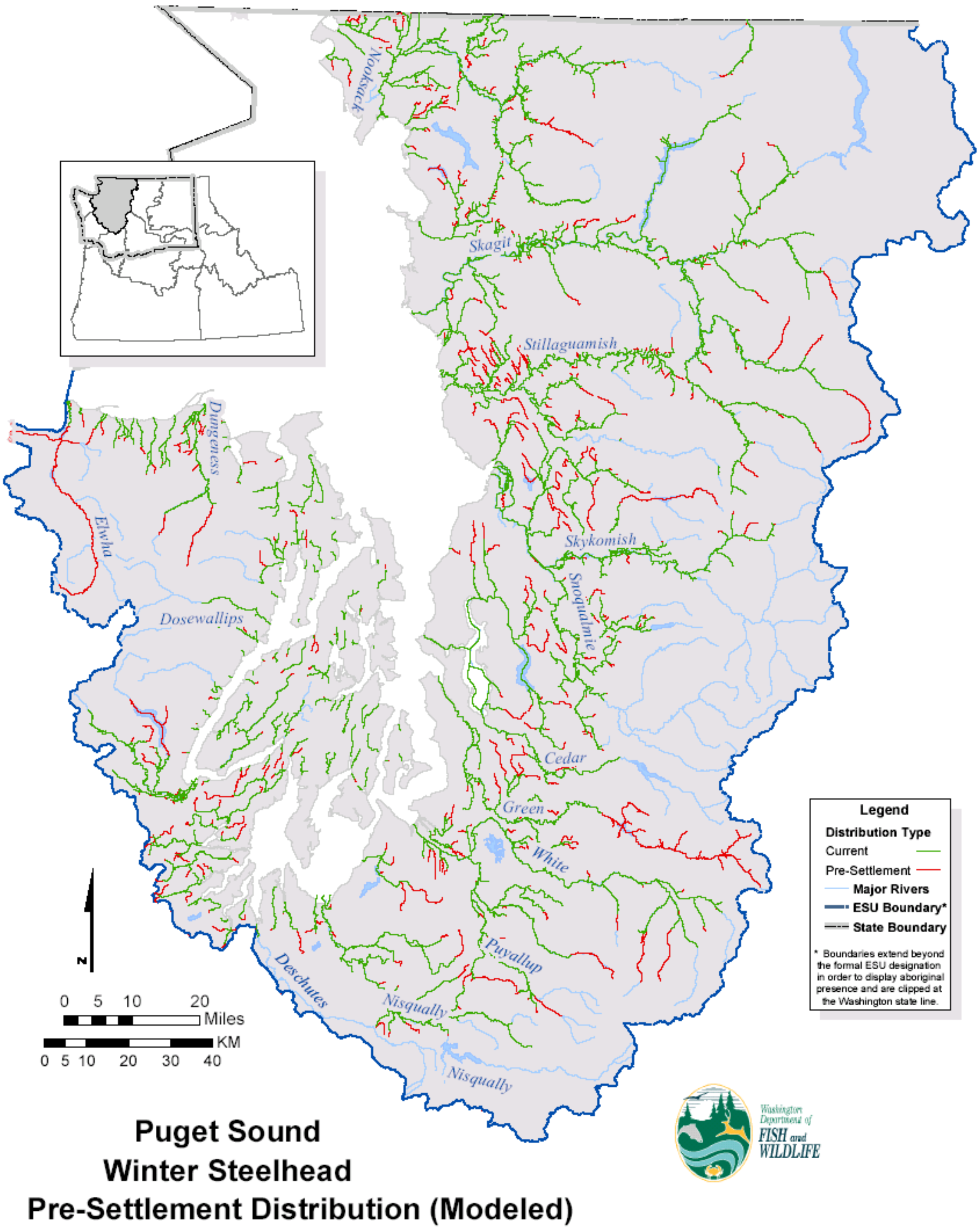

Figure 6-1. Current and predicted pre-settlement distribution of winter steelhead in the Puget Sound region.

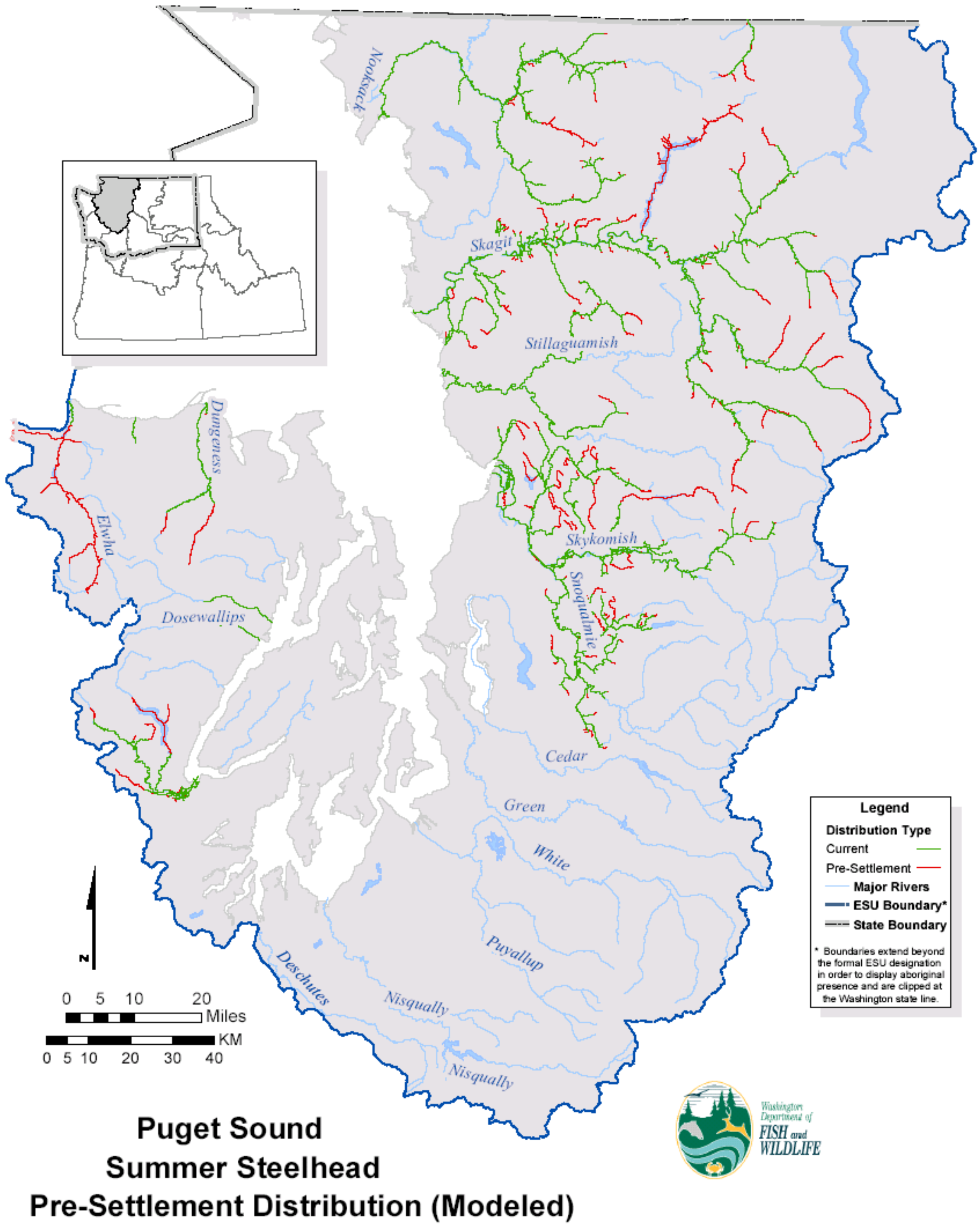

Figure 6-2. Current and predicted pre-settlement distribution of summer steelhead in the Puget Sound region.

Table 6-4. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Puget Sound region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
1 Nooksack					
Summer Steelhead	232-253	2	14-34	220	5% - 13%
Winter Steelhead	411-474	8	13-76	407	1% - 14%
3 Lower Skagit					
Summer Steelhead	165-203	0	0-38	165	0% - 19%
Winter Steelhead	230-277	0	0-47	230	0% - 17%
4 Upper Skagit					
Summer Steelhead	338-438	0	38-138	300	11% - 31%
Winter Steelhead	352-417	0	1-66	351	0% - 16%
5 Stillaguamish					
Summer Steelhead	114-124	0	0-10	114	0% - 8%
Winter Steelhead	245-333	72	0-88	317	-29% - 5%
7 Snohomish					
Summer Steelhead	431-570	0	1-140	431	0% - 24%
Winter Steelhead	433-562	0	1-130	432	0% - 23%
8 Cedar/Sammamish					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	183-226	0	0-44	183	0% - 19%
9 Green/Duwamish					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	175-225	0	59-109	116	34% - 48%
10 Puyallup/White					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	295-377	0	7-88	289	2% - 23%
11 Nisqually					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	171-198	0	7-33	165	4% - 17%
12 Chambers/Clover					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	29-33	0	0-29	29	0% - 11%
13 Deschutes					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	23-35	0	0-13	23	0% - 36%
14 Kennedy/Goldsborough					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	121-179	0	3-60	119	2% - 34%
15 Kitsap					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	163-175	0	1-13	163	0% - 7%
16 Skokomish/Dosewallips					
Summer Steelhead	110-125	0	17-32	93	16% - 25%
Winter Steelhead	143-157	0	19-32	125	13% - 20%

Table 6-4 (continued). Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Puget Sound region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
17 Quilcene/Snow					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	95-97	0	13-14	83	13% - 15%
18 Elwha/Dungeness					
Summer Steelhead	90-123	0	46-78	45	51% - 64%
Winter Steelhead	174-218	0	50-94	125	28% - 43%
Total					
Summer Steelhead	1,482-1,836	2	116-470	1,368	8% - 26%
Winter Steelhead	3,245-3,983	80	171-909	3,155	3% - 21%

Data were generally not available to evaluate changes in the spatial structure or diversity of steelhead in the Puget Sound region (Table 6-5). One exception is the Nisqually River, where the spatial structure of the Nisqually Winter population is predicted to have been reduced by 43% relative to pre-settlement conditions (J. Dorner, pers. comm.). Genetic analyses that compare the characteristics of winter steelhead from samples collected in the mid-1990s from the South Fork Nooksack River and Deer Creek have not yet been completed.

Table 6-5. Magnitude of changes in the spatial extent, spatial structure, and diversity for populations in Puget Sound with information available for spatial structure or diversity.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Dakota Creek Winter	Low – Moderate [1] (1%-14%)	Unknown	Unknown
Mainstem/NF Nooksack Winter		Unknown	Unknown
MF Nooksack Winter		Unknown	Unknown
SF Nooksack Winter		Unknown	[3]
Deer Creek Summer	Low [2] (0%-8%)	Unknown	[3]
SF Stillaguamish Summer		Unknown	Introduced Population
Canyon Creek Summer		Unknown	Unknown
Nisqually Winter	Low - Moderate (4%-17%)	High (43%)	Unknown

[1] Change in spatial extent is for all of WRIA 1 (Nooksack).

[2] Change in spatial extent is for all of WRIA 5 (Stillaguamish).

[3] Analysis not completed.

6.3.2 Olympic Peninsula

Watersheds in this ESU are unusual in that no hydroelectric or diversion dams block the access of steelhead to spawning areas that existed prior to European settlement. On the open Pacific side of the Olympic Peninsula ESU, many individual watersheds extend partly into the generally pristine habitat found in Olympia National Park. The lack of access points often makes it difficult to identify the upper extent of the distribution of steelhead. These factors result in substantial uncertainty in the percentage of the pre-settlement distribution of steelhead still accessible. Our analysis indicates a loss of 0-15% of the pre-settlement distribution of summer steelhead and a loss of 0%-28%for winter steelhead range (Table 6-6) (Figs. 6-3 and 6-4).

Table 6-6. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Olympic Peninsula region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
19 Lyre/Hoko					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	171-254	0	0-83	170	0% - 33%
20 Soleduck/Hoh					
Summer Steelhead	323-367	0	0-44	323	0% - 12%
Winter Steelhead	694-948	0	1-254	693	0% - 27%
21 Queets/Quinault					
Summer Steelhead	206-254	0	0-48	206	0% - 19%
Winter Steelhead	416-582	2	0-166	417	0% - 28%
Total					
Summer Steelhead	529-621	0	0-92	529	0% - 15%
Winter Steelhead	1,280-1,783	2	1-504	1,281	0% - 28%

A limited amount of information was available to evaluate changes in spatial structure and diversity in the Olympic Peninsula region (Table 6-7). Most notably, Currens (pers. comm.) evaluated changes in the genetic characteristics of the Pysht River Winter and Hoko River Winter steelhead populations. Comparing samples from 1975 and 1994, Currens noted that steelhead in both the Pysht River and Hoko River had become more like Chambers Creek steelhead during that period. Currens concluded that the magnitude of the change was “extremely unlikely” to have resulted only from genetic drift alone. “Although we cannot predict the direction of change due to genetic drift in any samples, the magnitude of the change, and the stronger similarity of Chambers Creek steelhead to Strait of Juan de Fuca samples than southern Puget Sound samples, it is highly likely that changes in these populations is due to interbreeding with

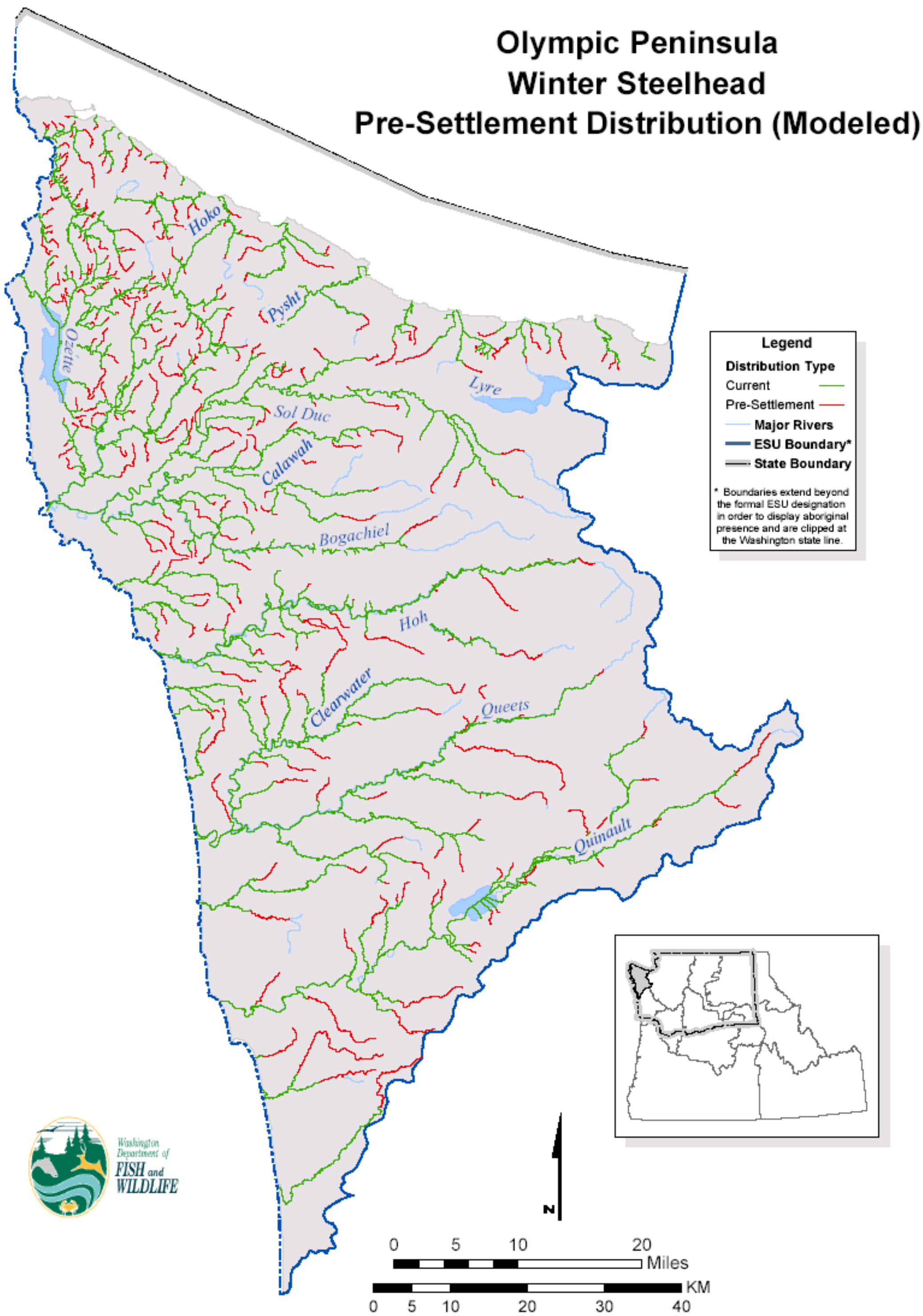

Figure 6-3. Current and predicted pre-settlement distribution of winter steelhead in the Olympic Peninsula region.

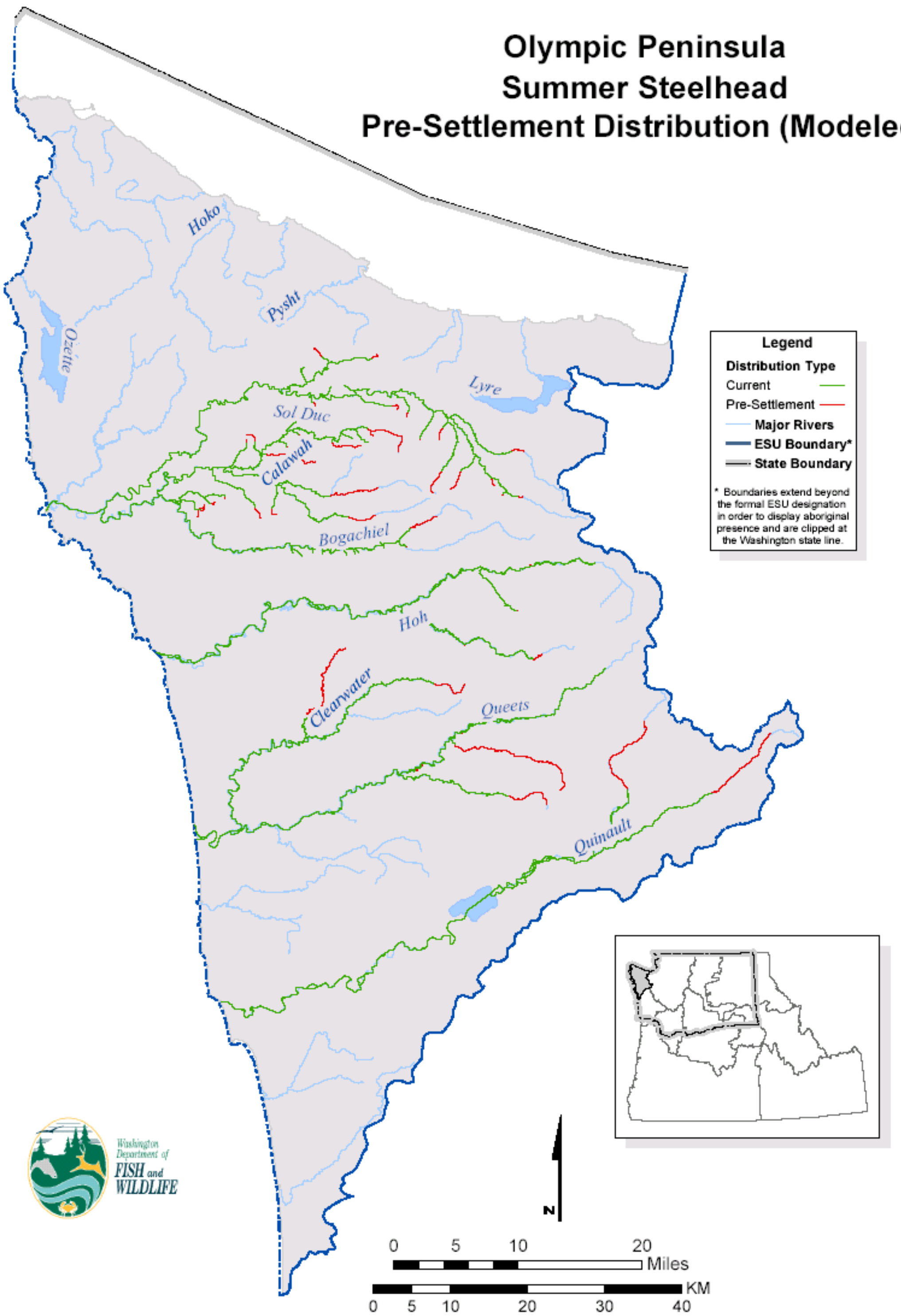

Figure 6-4. Current and predicted pre-settlement distribution of summer steelhead in the Olympic Peninsula region.

Chambers Creek steelhead." Similar analysis for samples from the Sol Duc River have not yet been completed.

Table 6-7. Magnitude of changes in the spatial extent, spatial structure, and diversity for populations in the Olympic Peninsula region with information available for spatial structure or diversity.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Pysht/Independents Winter	Low – Moderate [1] (0%- 33%)	Unknown	High. Estimated gene flow of 11-27% from nonlocal source.
Hoko Winter		Unknown	High. Estimated gene flow of 6-21% from nonlocal source.
Sol Duc Winter	Low – Moderate [2] (0%- 27%)	Unknown	[3]

[1] Change in spatial extent is for all of WRIA 19 (Lyre/Hoko).
[2] Change in spatial extent is for all of WRIA 20 (Soleduck/Hoh).
[3] Analysis not completed.

6.3.3 Southwest Washington

The distribution analysis indicates that a loss of 0%-14% of the pre-settlement distribution of summer steelhead and 3% - 31% loss for winter steelhead in the Southwest Washington region (Table 6-8)(Figs. 6-5 and 6-6). Two major factors limit fish distribution. The Wynoochee Dam blocks access to approximately 46 miles of summer steelhead habitat, and coal mining operations inhibit winter steelhead use of approximately 22 miles of habitat in Packwod and South Hanaford creeks.

Table 6-8. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Southwest Washington region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
22 Lower Chehalis					
Summer Steelhead	163-198	11	12-46	162	0% - 18%
Winter Steelhead	635-897	13	25-265	646	2% - 28%
23 Upper Chehalis					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	607-913	30	29-334	609	0% - 33%
24 Willapa					
Summer Steelhead	0	0	0	0	NA
Winter Steelhead	850-1,225	0	40-415	811	5% - 34%
25 Grays/Elochoman					
Summer Steelhead	59-59	0	0	59	0%
Winter Steelhead	464-586	0	21-142	443	4% - 24%
Total					
Summer Steelhead	222-257	11	12-46	222	0% - 14%
Winter Steelhead	2,580-3,621	43	114-1,156	2,509	3% - 31%

Predictions of the change in spatial structure are not available for any populations in the Willapa subregion or for two summer steelhead populations in the Grays Harbor subregion. Analysis indicates that the spatial structure of the remainder of the winter steelhead populations in the Grays Harbor and Columbia Mouth subregions has been reduced by an average of 11% (Table 6-9). The predicted loss of diversity is slightly greater in the Grays Harbor region (13%) than in the Columbia Mouth subregion (7%).

Predictions of the changes in the spatial structure of winter steelhead populations in the Grays Harbor subregion are available through a study funded by the Chehalis Basin Fisheries Task Force, WDFW, U.S. Fish and Wildlife Service, and the U.S. Army Corps of

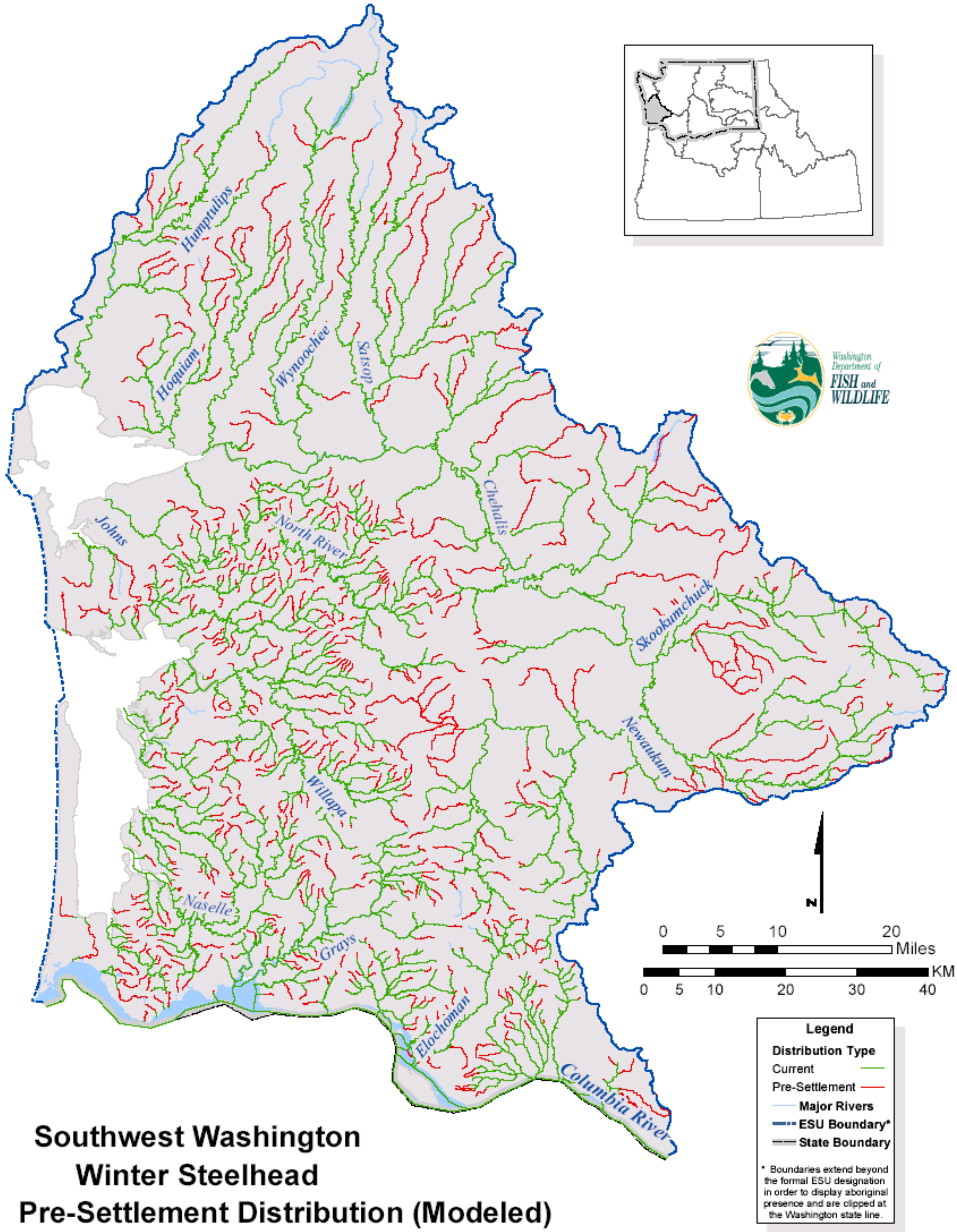

Figure 6-5. Current and predicted pre-settlement distribution of winter steelhead in the Southwest Washington region.

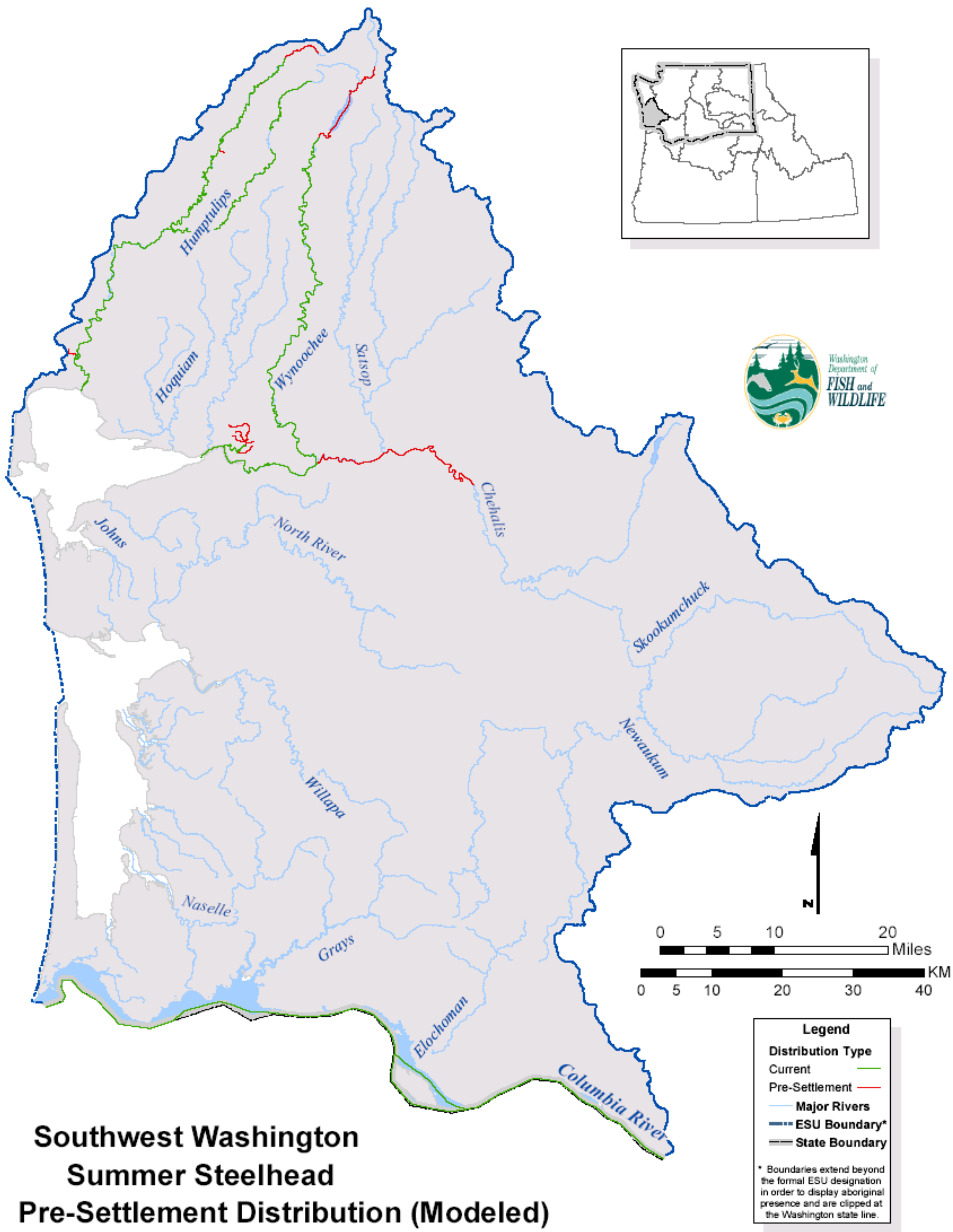

Figure 6-6. Current and predicted pre-settlement distribution of summer steelhead in the Southwest Washington region.

Engineers (Mobrand Biometrics 2003)(Table 6-9). The analysis indicates a more than 20% loss of spatial structure for the Chehalis Winter, Skookumchuck-Newaukum Winter, and South Bay Winter populations. Winter steelhead populations in Grays Harbor are predicted to have lost an average 13% of the spatial structure that existed prior to European settlement.

Analyses for the populations in the Columbia Mouth subregion show a similar range in the percent of spatial structure lost (Table 6-9). The Grays Winter population is predicted to have the largest loss (23%) in spatial structure; a slight increase (3%) is predicted for the Germany Winter population.

No information is available to evaluate the within-population diversity for populations in the Southwest Washington region.

Table 6-9. Magnitude of changes in the spatial extent, spatial structure and diversity of extant populations of steelhead in the Grays Harbor and Columbia Mouth subregions.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Grays Harbor Summer			
Chehalis Summer	Low – Moderate[1] (0%-18%)	Unknown	Unknown
Humptulips Summer		Unknown	Unknown
Summer Average	Low- Moderate (0%-18%)	Unknown	Unknown
Grays Harbor Winter			
Hoquiam Winter	Low – Moderate [1] (2%-28%)	Low (9%)	Unknown
Humptulips Winter		Moderate (16%)	Unknown
Satsop Winter		Low (0%)	Unknown
South Bay Winter		Moderate (20%)	Unknown
Wishkah Winter		Low (3%)	Unknown
Wynoochee Winter		Moderate (11%)	Unknown
Chehalis Winter	Low – High [2] (1%-31%)	Moderate (23%)	Unknown
Skookumchuck/Newaukum Winter	Low – High [3] (0%-33%)	Moderate (26%)	Unknown
Winter Average	Low –High (1% - 31%)	Moderate (13%)	Unknown
Columbia Mouth			
Abernathy-Germany-Mill Winter	Low – High [4] (4%-24%)	Low (2%)	Unknown
Elochoman-Skamokawa Winter		Moderate (13%)	Unknown
Grays Winter		Moderate (23%)	Unknown
Average	Low - Moderate (4%-24%)	Moderate (13%)	Unknown
Southwest Washington Average			
Summer	Low – Moderate (0% - 14%)	Unknown	Unknown
Winter	Low – High (0% - 31%)	Moderate (11%)	Unknown

[1] Change in spatial extent is for all of WRIA 22 (Lower Chehalis).
[2] Change in spatial extent is for all of WRIA 22 (Lower Chehalis) and WRIA 23 (Upper Chehalis).
[3] Change in spatial extent is for all of WRIA 23 (Upper Chehalis).
[4] Change in spatial extent is for all of WRIA 25 (Grays/Elochoman).

6.3.4 Lower Columbia River

Substantial reductions and one increase in the distribution of steelhead have occurred in the Lower Columbia River region (Table 6-10)(Figs. 6-7 and 6-8). A hydroelectric dam on the Lewis River has reduced the pre-settlement distribution of summer steelhead by 34% - 45% and for winter steelhead by 13% - 28%. Although trap-and-haul operations distribute winter steelhead to the Tilton, Cispus, and Upper Cowlitz rivers, approximately 21 miles of habitat accessible prior to European settlement is now covered by reservoirs. A substantial extension of the distribution of winter steelhead occurred in the Wind River when a fishway was provided at Shepard Falls. With the addition of the fishway, the current distribution of winter steelhead is 156% of the pre-settlement distribution.

Table 6-10. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Lower Columbia River region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
26 Cowlitz					
Summer Steelhead	9	0	0	9	0%
Winter Steelhead	1,040–1,296	12	112-367	941	10% - 27%
27 Lewis					
Summer Steelhead	431-521	0	146-237	285	34% - 45%
Winter Steelhead	414-500	95	148-234	362	13% - 28%
28 Salmon/Washougal					
Summer Steelhead	208-246	0	3-40	205	1% - 16%
Winter Steelhead	298-356	0	9-67	289	3% - 19%
29 Wind/White Salmon					
Summer Steelhead	213-257	0	31-75	182	15% - 29%
Winter Steelhead	128-129	106	34-35	200	-55% - 56%
Total					
Summer Steelhead	861-1,034	0	180-353	681	21% - 34%
Winter Steelhead	1,881-2,280	213	304-702	1,791	5% - 21%

The spatial structure index was computed for many populations of steelhead in the Lower Columbia region during the development of the Lower Columbia recovery plan (LCFRB 2004) (Table 6-11). In general, the indices showed a greater loss in spatial structure for populations of winter steelhead (40%) than summer steelhead (12%). The disparity between summer and winter steelhead appeared to be due to two factors. First, summer steelhead often used upper reaches of watersheds where habitat is in

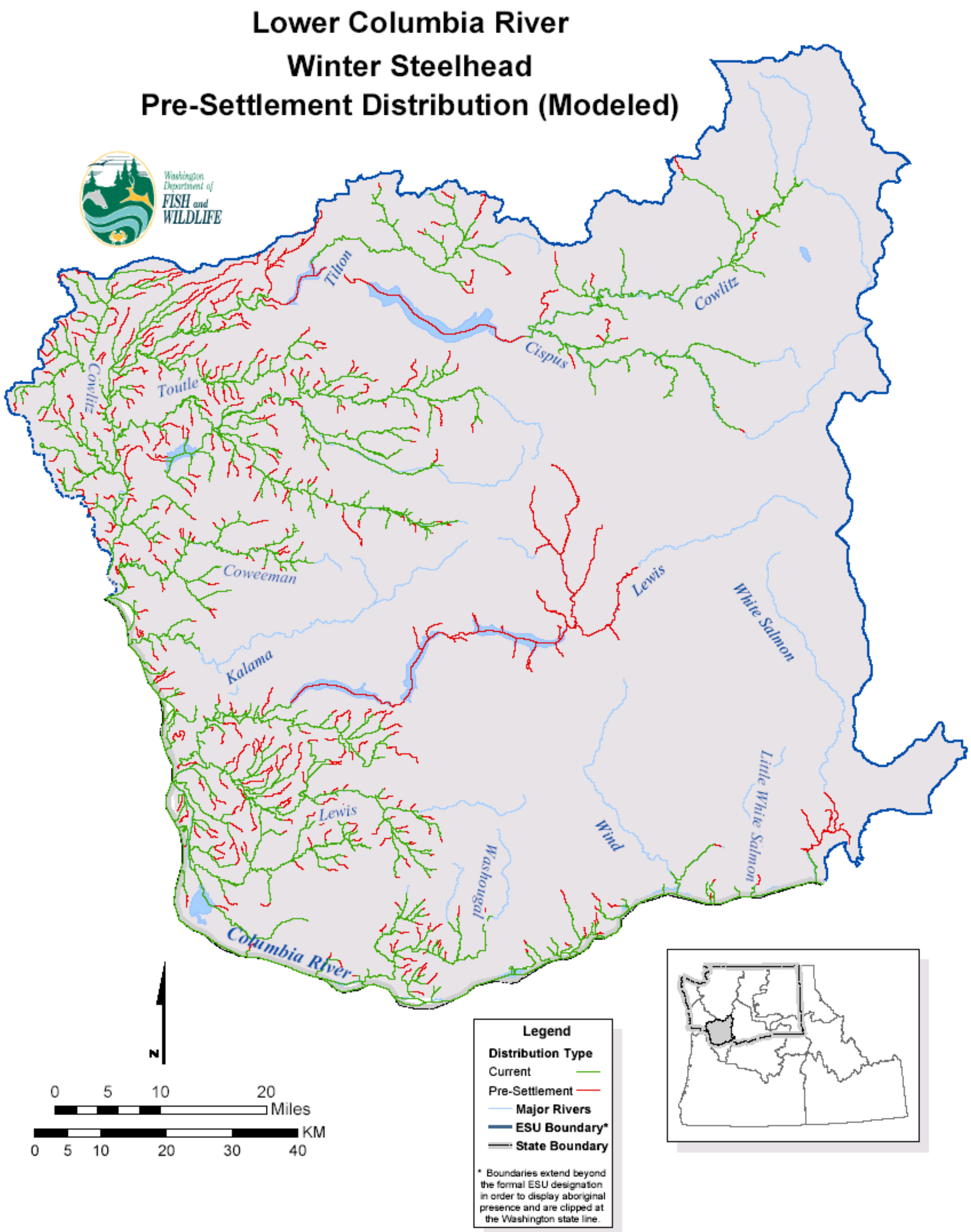

Figure 6-7. Current and predicted pre-settlement distribution of winter steelhead in the Lower Columbia River region.

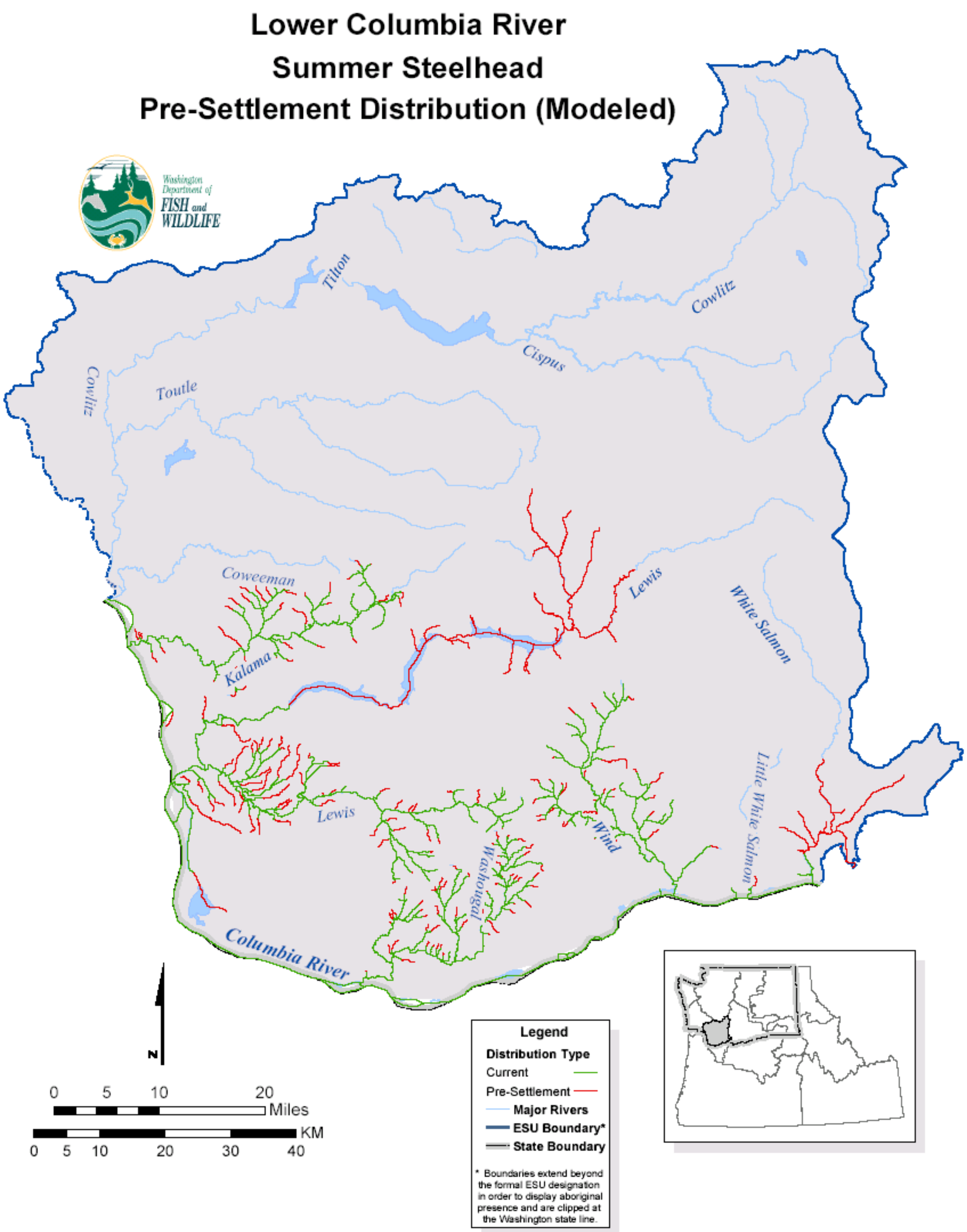

Figure 6-8. Current and predicted pre-settlement distribution of summer steelhead in the Lower Columbia River region.

better condition. Second, summer steelhead were not historically present in some watersheds with substantial habitat degradation (e.g., Toutle River, Salmon Creek). The loss in spatial structure was predicted to be greatest for the Tilton (79%), Lower Cowlitz Winter (77%), Lower Gorge Winter (62%), and Salmon Winter (61%) populations.

Table 6-11. Magnitude of changes in the spatial extent, spatial structure, and diversity of extant populations of steelhead in the Lower Columbia region.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Lower Columbia Winter			
Cispus Winter	Moderate [1] (10%-27%)	Moderate (13%)	High
Upper Cowlitz Winter		Moderate (16%)	
Tilton Winter		High (79%)	High
Lower Cowlitz Winter		High (77%)	High
Toutle Winter [2]		High (55%)	Unknown
Coweeman Winter		Moderate (14%)	Unknown
Kalama Winter	Moderate [3] (13%-28%)	Low (9%)	[5]
NF Lewis Winter		High (50%)	Unknown
EF Lewis Winter		Moderate (23%)	Unknown
Salmon Winter	Low – Moderate [4] (3%-19%)	High (61%)	Unknown
Washougal Winter		Moderate (28%)	Unknown
Lower Gorge Winter		High (62%)	Unknown
Wind Winter	Increase	High (41%)	Unknown
Lower Columbia Summer			
Kalama Summer	High (34%-45%)	Low (0%)	Unknown
EF Lewis Summer		Low (6%)	Unknown
Washougal Summer	Low – Moderate (1%-16%)	Moderate (28%)	Unknown
Wind Summer	Moderate (15%-29%)	Moderate (12%)	Unknown
Lower Columbia Average			
Summer	Moderate – High (21%-34%)	Moderate (12%)	
Winter	Low – Moderate (5%-21%)	High (40%)	

[1] Change in spatial extent is for all of WRIA 26 (Cowlitz).
[2] Mainstem/NF Toutle, Green, and South Fork Toutle populations aggregated for this analysis.
[3] Change in spatial extent is for all of WRIA 27 (Lewis).
[4] Change in spatial extent is for all of WRIA 28 (Salmon/Washougal).
[5] Genetic analyses not completed.

Information to evaluate reductions in within-population diversity is generally not available for populations within the Lower Columbia region. Loss of genetic diversity for the four Cowlitz populations was categorized as High because of the development of a composite broodstock after the completion of Mayfield Dam. Genetic analyses that compare the characteristics of winter steelhead from samples from the Kalama River in 1994 and prior to 1975 have not yet been completed.

6.3.5 Middle Columbia River

A substantial reduction in the range of summer steelhead has occurred in the Middle Columbia River region (Table 6-12)(Figs 6-9 and 6-10). The greatest reduction in the pre-settlement range has occurred in the Upper Yakima (48%-52%), but substantial reductions are also estimates to have occurred in the Naches (21%-24%) and Rock/Glade (18%-25%) WRIAs. Significant impediments to steelhead distribution in the Yakima River and tributaries are briefly discussed below.

> Rimrock Dam. The Tieton River is a tributary to the Naches River. Tieton Dam blocks access to approximately 48 miles of the upper Tieton River.
>
> Bumping Dam. The Bumping River is a tributary to the Naches River. Bumping Dam blocks access approximately 12 miles of the upper Bumping River.
>
> Cle Elum Dam. The Cle Elum River is a tributary to the upper Yakima River. Cle Elum Dam blocks access to approximately 35 miles of the upper Cle Elum River.
>
> Kachess Dam. The Kachess River is a tributary to the upper Yakima River. Kachess Dam blocks access to approximately 14 miles of the upper Kachess River.
>
> Keechelus Dam. Blocks access to approximately 13 miles of the headwaters of the Yakima River.

Habitat degradation and fragmentation have resulted in a substantial reduction in the spatial structure index for populations in the Middle Columbia River region (Table 6-13). The average loss is 77% and 3 of the 4 populations in the Yakima River are predicted to have lost more than 85% of the spatial structure present prior to European settlement. Smaller but substantial reductions (42%) in spatial structure are predicted for the Klickitat and Satus populations. Freundenthal et al. (2005) found that the gap between the Dry Creek and Satus/Logy MSAs was increasing and concluded that this resulted in a moderate risk to the population.

The within-population diversity of populations within the Yakima subbasin have been extensively analyzed (Busack et al. 2005; Freudenthal et al. 2005). Analysis of microsatellite genetic data suggests slight introgression of Skamania-type steelhead into the Naches and Upper Yakima populations (Busack et al. 2005). Samples of approximately 100 juvenile steelhead were collected at Roza Dam (sampled in 2000, 2001, and 2003), the Naches River (sampled in 2004), Toppenish Creek (sampled in 2000

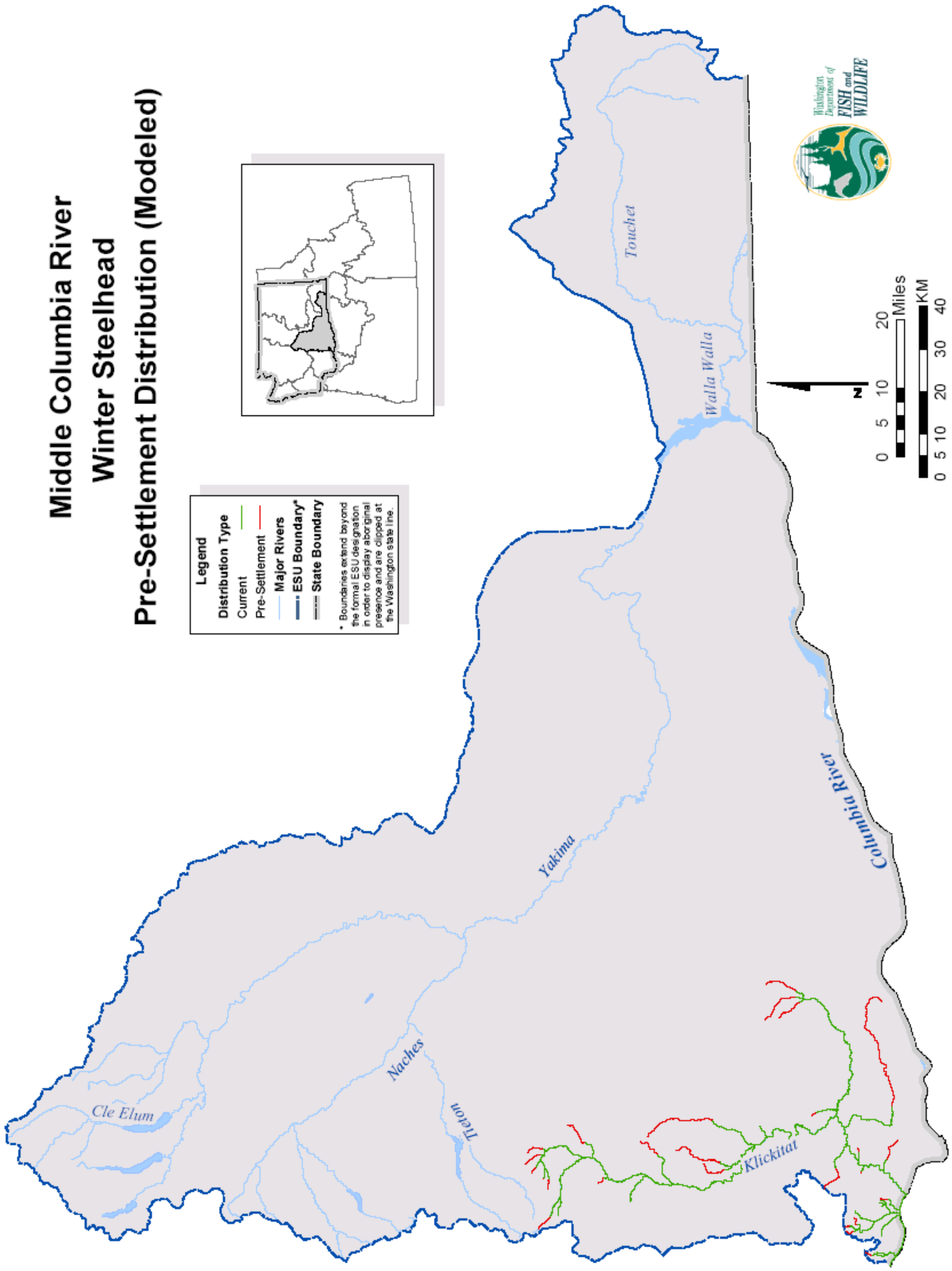

Figure 6-9. Current and predicted pre-settlement distribution of winter steelhead in the Middle Columbia River region.

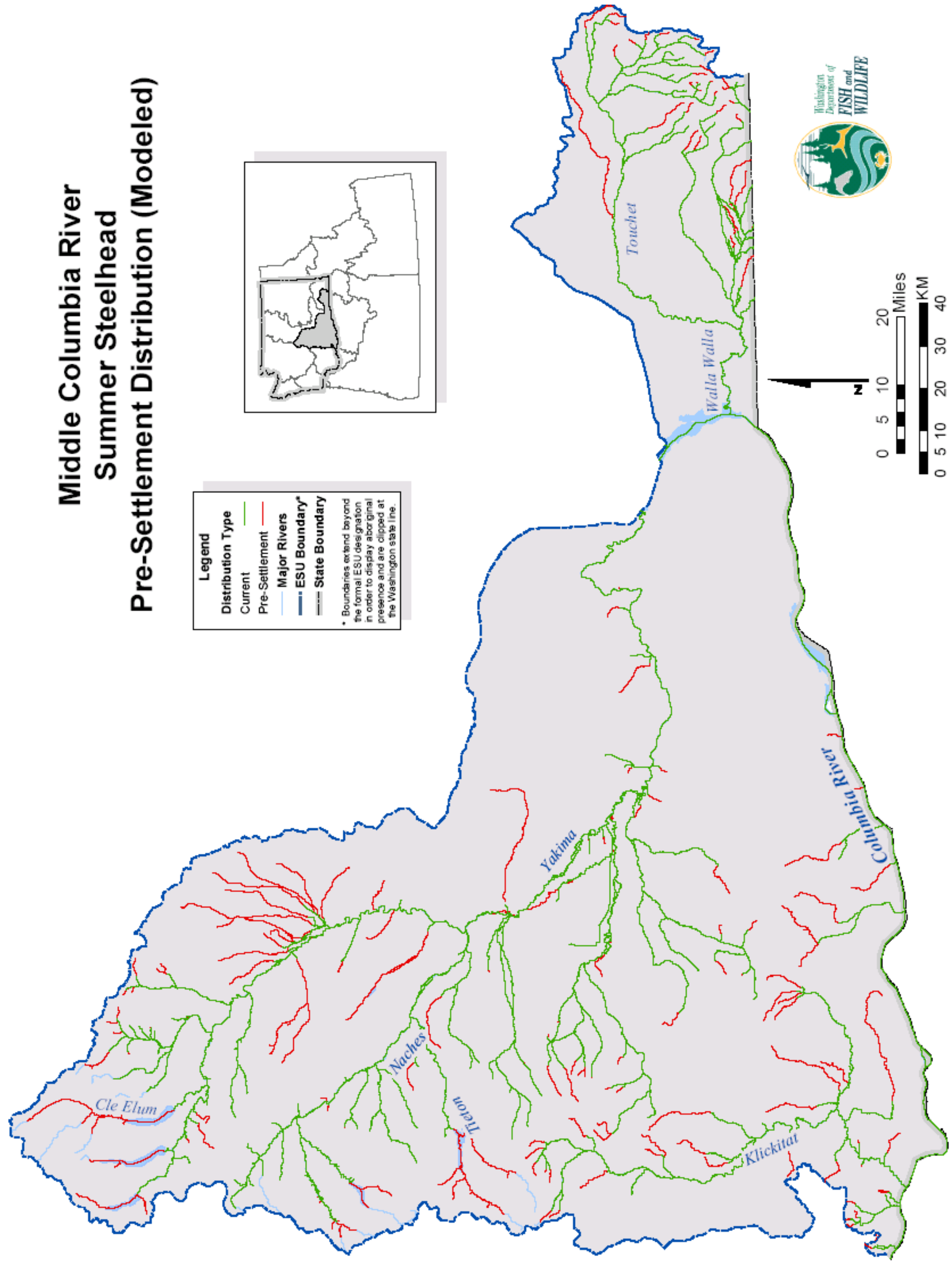

Figure 6-10. Current and predicted pre-settlement distribution of summer steelhead in the Middle Columbia River region.

and 2001), and Satus Creek (sampled in 2000 and 2001). Analysis using the STRUCTURE program (Pritchard et al. 2000) indicated that 6-9% of the multi-locus genotype of an average steelhead juvenile sampled in the Naches River or at Roza Dam was consistent with Skamania-type fish. The range was lower, 2-4%, for the samples from Toppenish Creek and Satus Creek. These slight relationships to Skamania-type fish could also be artifacts of shared polymorphisms or shared ancestry rather than introgression (Utter 1998; Busack et al. 2005).

Introgression with hatchery-origin rainbow trout may also have occurred in the Naches and Upper Yakima populations (Campton and Johnston 1985; Phelps et al. 2000). Phelps et al. (2000) concluded from an admixture analysis of parental source (Long 1991) that hatchery-origin rainbow trout were responsible for more than 10% of the gene pool for samples from Wilson Creek (Upper Yakima tributary) and the Roza trap. Although the release of exogenous resident and anadromous salmonids into the Yakima subbasin has ceased, we categorized the loss of diversity of the Naches and Upper Yakima populations as Moderate because of the residual effects that are remain evident.

Phenotypic traits of the steelhead populations in the Yakima subbasin appear to have been affected in several ways (Freudenthal et al. 2005).

> Juvenile Residence. Short and long-term juvenile rearing strategies in the Naches and Toppenish have been affected by reduced summer flows. Conversely, juvenile residence has been prolonged in the Upper Yakima by increased summer flows and decreased summer temperatures.
>
> Adult Entry. Return timing of adults in all four populations appears to have been delayed by reduced flow and high temperatures in the mainstem of the Yakima River.

Juveniles originating from a non-local GDU (Lyons Ferry) have been released into the Touchet River since 1985 (Schuck 1998). Genetic analysis has been conducted to assess the extent of introgression from the Lyons Ferry stock. Bumgarner et al (2003; 2004) concluded that “the Touchet River wild-stock collections remain distinct from the LFH hatchery stock. Some of this distinction indicates that LFH summer steelhead stock have failed to introgress into the wild-stock population in the Touchet drainage. This conclusion has also been supported from the Dayton adult trap data that suggests that very few hatchery-origin return to the natural spawning areas on the Touchet River”.

No information was available to assess the spatial structure or diversity of the Rock Creek population.

Table 6-12. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer and winter steelhead in the Middle Columbia River region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
30 Klickitat					
Summer Steelhead	249-398	0	0-149	249	0% - 37%
Winter Steelhead	209-300	0	0-91	209	0% - 30%
31 Rock/Glade					
Summer Steelhead	192-210	0	34-52	158	18% - 25%
Winter Steelhead	0	0	0	0	NA
32 Walla Walla					
Summer Steelhead	551-654	0	9-113	541	2% - 17%
Winter Steelhead	0	0	0	0	NA
37 Lower Yakima					
Summer Steelhead	617-698	0	31-113	586	5% - 16%
Winter Steelhead	0	0	0	0	NA
38 Naches					
Summer Steelhead	333-347	0	70-84	263	21% - 24%
Winter Steelhead	0	0	0	0	NA
39 Upper Yakima					
Summer Steelhead	517-590	0	233-306	284	45% -52%
Winter Steelhead	0	0	0	0	NA
Total					
Summer Steelhead	2,459-2,898	0	378-816	2,082	15%-28%
Winter Steelhead	209-300	0	0-91	209	7% - 30%

Table 6-13. Magnitude of changes in the spatial extent, spatial structure, and diversity of extant populations of steelhead in the Middle Columbia River region.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Klickitat Summer-Winter	Low – High (0-66%)	High (42%) [1]	Unknown
Rock	Moderate (18%-25%)	Unknown	Unknown
Touchet	High Loss of 1 of 2 MSAs	High (91%)	Low
Walla Walla [2]		High (95%)	Unknown
Satus	Low – Moderate [4] (5%-16%)	High (58%)	Low
Toppenish		High (87%)	Moderate
Naches	Moderate (21%-24%)	High (88%)	Moderate
Upper Yakima	High Loss of 8 of 11 MSAs	High (92%)	Moderate
Middle Columbia River Average	Moderate (15%-28%)	High (77%)	

[1] Four separate analyses were completed for the Klickitat River: 1) summer and winter life history and distribution characteristics; and 2) above and below Castille Falls. Reported index is average value for summer and winter steelhead below Castille Falls.
[2] Analysis was run separately for the mainstem Walla Walla River and tributaries. Reported index is average value for two analyses.

6.3.6 Upper Columbia River

Approximately 43%-52% of the pre-settlement distribution of steelhead has been lost in the Upper Columbia region (Table 6-14)(Fig. 6-11). Although the majority of this is above Grand Coulee Dam, substantial reductions in the distribution of steelhead are evident in other subbasins as well. These include the Entiat (14% - 16% loss), Wenatchee (10% - 34% loss), and Okanogan (0% - 25% loss).

Major barriers include the following. Approximately 22 miles of Icicle Creek, a tributary to the Wenatchee, are blocked by a USFWS hatchery. On the Okanogan River, approximately 30 miles of habitat are blocked by a dam on Salmon Creek.

Table 6-14. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer steelhead in the Upper Columbia River region.

WRIA	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
36 Esquatzel Summer Steelhead	105	0	0	105	0%
41 Lower Crab Summer Steelhead	128-181	0	0-53	128	0% - 29%
44 Moses Coulee Summer Steelhead	44-60	0	21-37	23	47% - 62%
45 Wenatchee Summer Steelhead	257-351	0	27-120	231	10% - 34%
46 Entiat Summer Steelhead	96-98	0	14-15	82	14% - 16%
47 Chelan Summer Steelhead	27	0	0	27	0%
48 Methow Summer Steelhead	226-303	0	0-77	226	0% - 26%
49 Okanogan Summer Steelhead	145-195	0	0-50	145	0% - 25%
50 Foster Summer Steelhead	53-55	0	42-45	11	80% - 81%
Above Grand Coulee Dam Summer Steelhead	644	0	644	0	100%
Total Summer Steelhead	1,726-2,018	0	749-1,040	978	43% - 52%

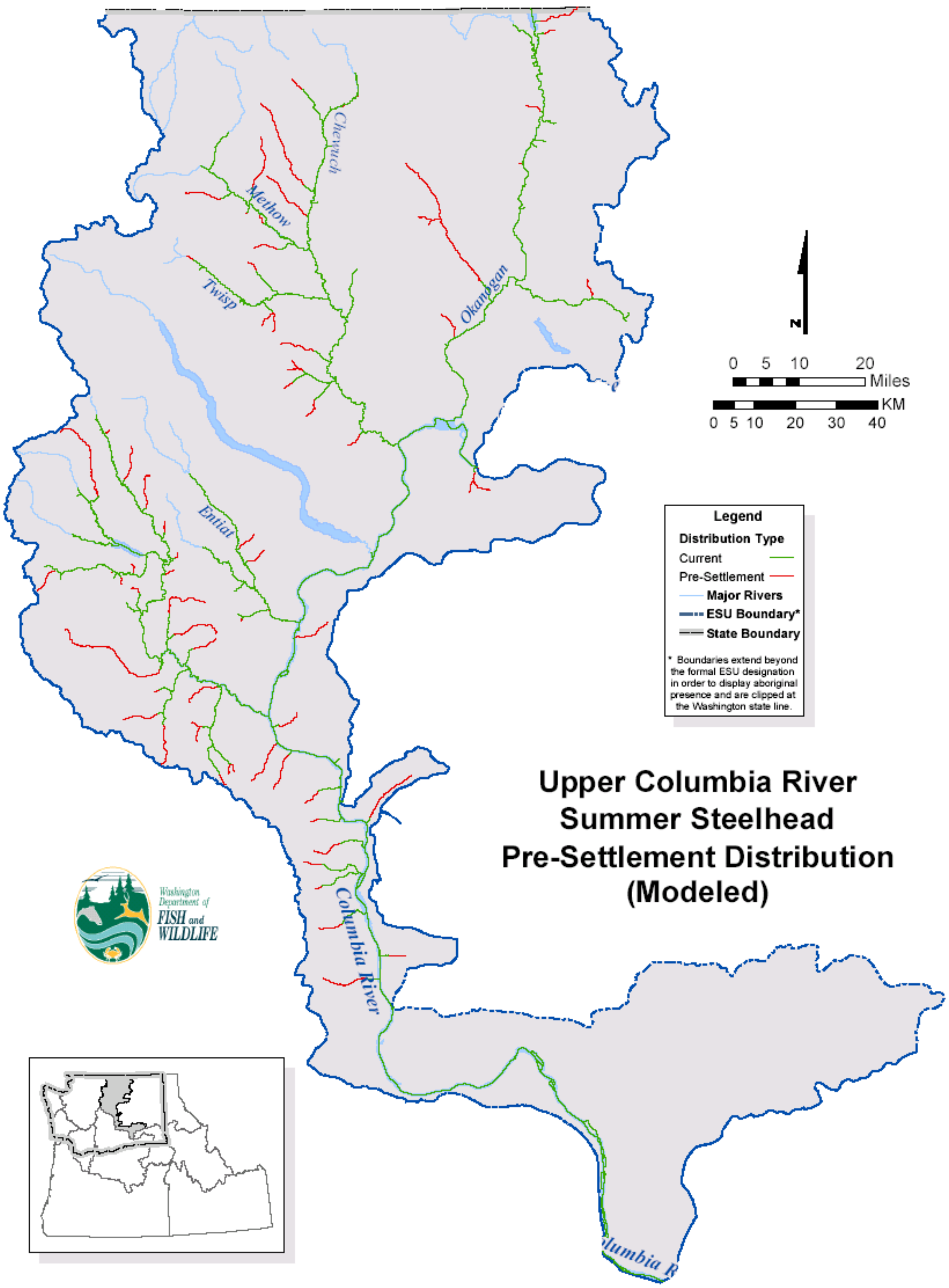

Figure 6-11. Current and predicted pre-settlement distribution of summer steelhead in the Upper Columbia River region.

Predictions of the spatial structure index are available for three steelhead populations in the Upper Columbia region (Table 6-15). The average loss in diversity is predicted to be 79%, with 98% of the diversity predicted to have been lost for the Okanogan population.

The diversity of the Wenatchee, Entiat, Methow, and Okanogan populations of steelhead has been affected by a series of artificial production programs. The Grand Coulee Fish Maintenance Project (Fish and Hanavan 1948) probably resulted in the mixing of steelhead from all areas upstream of Rock Island Dam and artificial production programs subsequently released juvenile steelhead of unknown origin throughout the Upper Columbia region. We categorized the diversity loss of the Okanogan population as High because the large reduction in the abundance has likely had a substantial effect on diversity.

Table 6-15. Magnitude of changes in the spatial extent, spatial structure, and diversity of extant populations of steelhead in the Upper Columbia region.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Crab Creek	Low – Moderate (0%-29%)	Unknown	Unknown
Wenatchee	Moderate - High (10%-34%) Loss of 1 of 4 MSAs	High (73%)	High
Entiat	Moderate (14%-16%)	High (100%)	High
Methow	Low – Moderate (0%-26%)	High (65%)	High
Okanogan	Low - Moderate (0%-25%)	High (98%)	High
Upper Columbia River Average [1]	Moderate - High (11%-31%)	High (79%)	Unknown

[1] Average is only for the five extant populations in the Upper Columbia ESU.

6.3.7 Snake River Basin

Relative to the remainder of the ESU, a relatively small reduction (2%-12%) in the distribution of steelhead has occurred in the Washington component of the Snake River Basin region (Table 6-16).

Table 6-16. Pre-settlement distribution, range extensions, range contractions, and current distribution of summer steelhead in the Snake Basin ESU.

	Pre-Settlement Distribution (miles)	Range Extension (miles)	Range Contraction (miles)	Current Distribution (miles)	Percent Lost
33 Lower Snake Summer Steelhead	67	0	0	67	0%
34 Palouse Summer Steelhead	8	0	0	8	0%
35 Middle Snake Summer Steelhead	913-1,016	0	20-123	893	2% - 12%
Total Summer Steelhead	988-1,091	0	20-123	968	2% - 11%

Spatial structure is predicted to have been reduced by an average of 62% in the Washington component of the Snake River basin (Table 6-17). The largest reduction is predicted for the Asotin population (82%) and the smallest for the Joseph population (48%).

The diversity of steelhead in the Tucannon River may have been affected by the release of juveniles that originated from broodstock from a nonlocal GDU. Juvenile steelhead of Lyons Ferry, Wells, and Wallowa origin have been released into the Tucannon River since 1982 (Schuck 1998). Adults originating from releases of Lyons Ferry type juveniles comprised an average of 70% of the total number of fish sampled at a trap on the lower Tucannnon River (Bumgarner et al. 2003; 2004). Genetic analysis indicates that the Tucannon population remains distinct from the Lyons Ferry, but some introgression has occurred (Bumgarner et al. 2003; 2004). The magnitude of diversity loss is High for the Tucannon River because of the high incidence of Lyons Ferry origin spawners.

Limited information is available to evaluate the diversity of populations in the Grande Ronde River and Asotin Creek. Two artificial production programs release juveniles from a broodstock (Wallowa) initiated with adults collected outside of this GDU. Estimates are not available for the percentage of spawners originating from hatchery

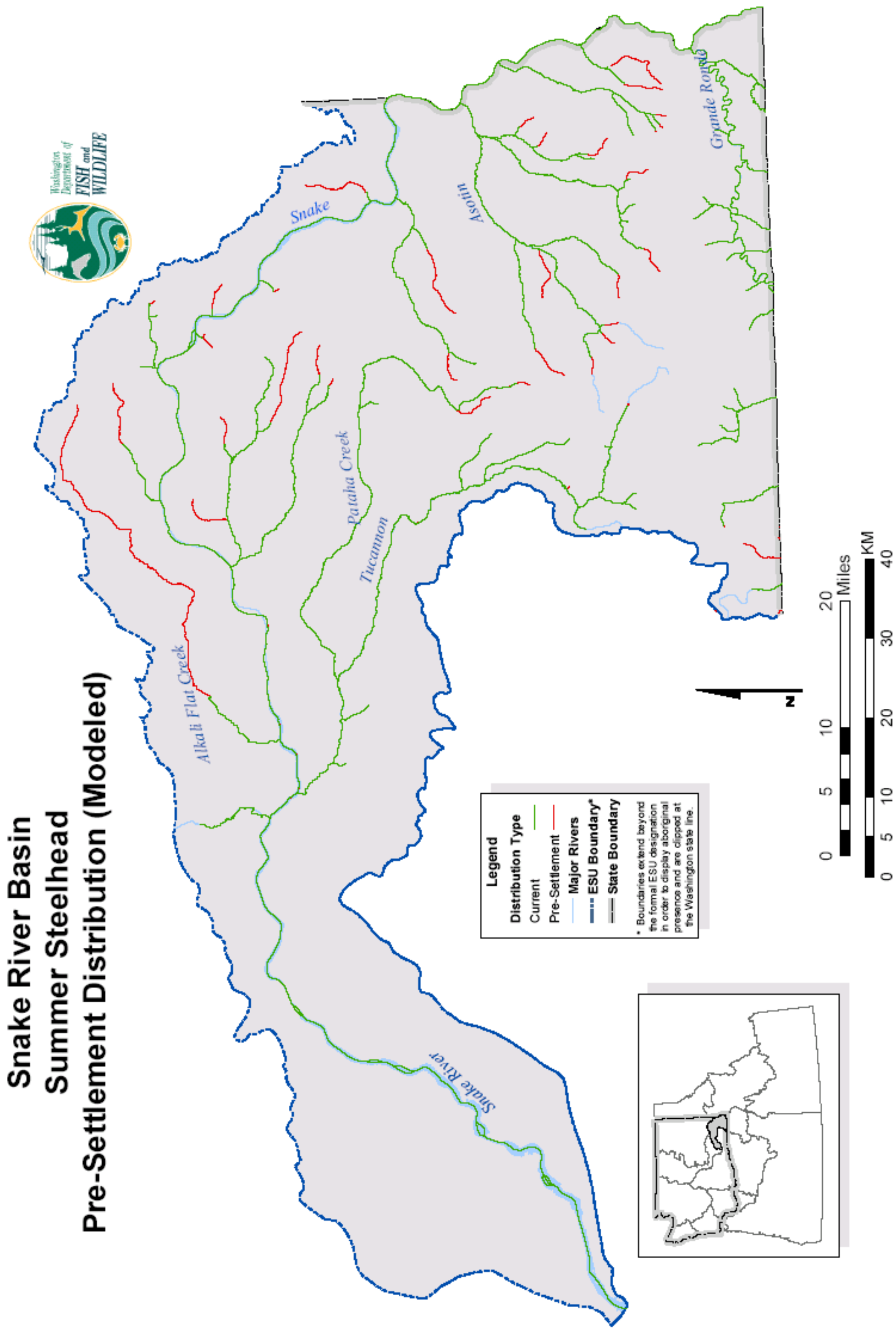

Figure 6-12. Current and predicted pre-settlement distribution of summer steelhead in the Snake River Basin region.

releases. However, NMFS (2004) reviewed data from several traps and hatcheries in the Grande Ronde system and concluded, “there is some information that straying to other Grande Ronde natural production areas is small”. NMFS(2004) also reported that “hatchery steelhead have not been reported from Joseph Creek”.

Table 6-17. Magnitude of changes in spatial extent, spatial structure, and diversity of extant populations of steelhead in the Washington component of the Snake River Basin region.

Population	Reduction in Spatial Extent	Reduction in Spatial Structure	Reduction in Diversity
Asotin	Low- Moderate [1] (2%-11%)	High (82%)	Unknown
Tucannon		High (66%)	High
Lower Grande Ronde		High (51%)	Unknown
Joseph		High (48%)	Unknown
Snake River Basin Average	Low – Moderate (2% - 11%)	High (62%)	

[1] Change in spatial extent is for all of WRIAs 33 (Lower Snake), 34 (Palouse), and 35 (Middle Snake).

6.4 Discussion

This analysis provides the first cross-state assessment of spatial structure and diversity for any salmonid species in Washington. The results suggest a substantial loss of spatial structure and diversity of steelhead populations in some regions of the state, but also highlight the need for significant improvements in monitoring and analysis.

The reduction in the range of steelhead in Washington was estimated as 9%-27% for winter steelhead and 17%-30% for summer steelhead (Fig. 6-13). Substantial variation existed across the regions, with the smallest reduction in the Snake River Basin region (2%-11%) and the largest reduction in the Upper Columbia River region (43%-52%). Substantial uncertainty existed in the estimate for the reduction of the range in many regions. This was perhaps most evident in the Olympic Peninsula region, where the lack of access points often makes it difficult to identify the upper extent of the distribution of steelhead. The lack of certainty also reflects that only a single variable, gradient, was used in the GIS model to predict the distribution of steelhead.

Despite these limitations, the GIS analysis proved to be a valuable, cost effective method for analyzing spatial data. The graphical display of distribution and barrier data in SalmonScape provided a rapid means to evaluate and check the distribution information, location of populations, and barriers limiting access. The value of the GIS analysis could be substantially enhanced by creating spatial data layers with barriers, by incorporating other variables into the model for predicting fish distribution, and by annually mapping the actual distribution of redds. Mapping the distribution of redds now and in the future will be invaluable as we begin to assess the effectiveness of recovery actions.

A substantial loss in the spatial structure and connectivity of steelhead populations is evident for populations in Washington for which the spatial structure index could be computed (Fig. 6-14). The index was generally not available for populations in the Puget Sound region, Olympic Peninsula region, or the Willapa Bay subregion. In the remainder of the regions, 52% of the populations had a High reduction, 32% had a Moderate reduction, and 16% had a Low reduction in spatial structure and connectivity. All of the populations in the Middle Columbia River, Upper Columbia River, and Snake River basin regions for which an index was computed had a High loss (>30%) of spatial structure (Fig. 6-15).

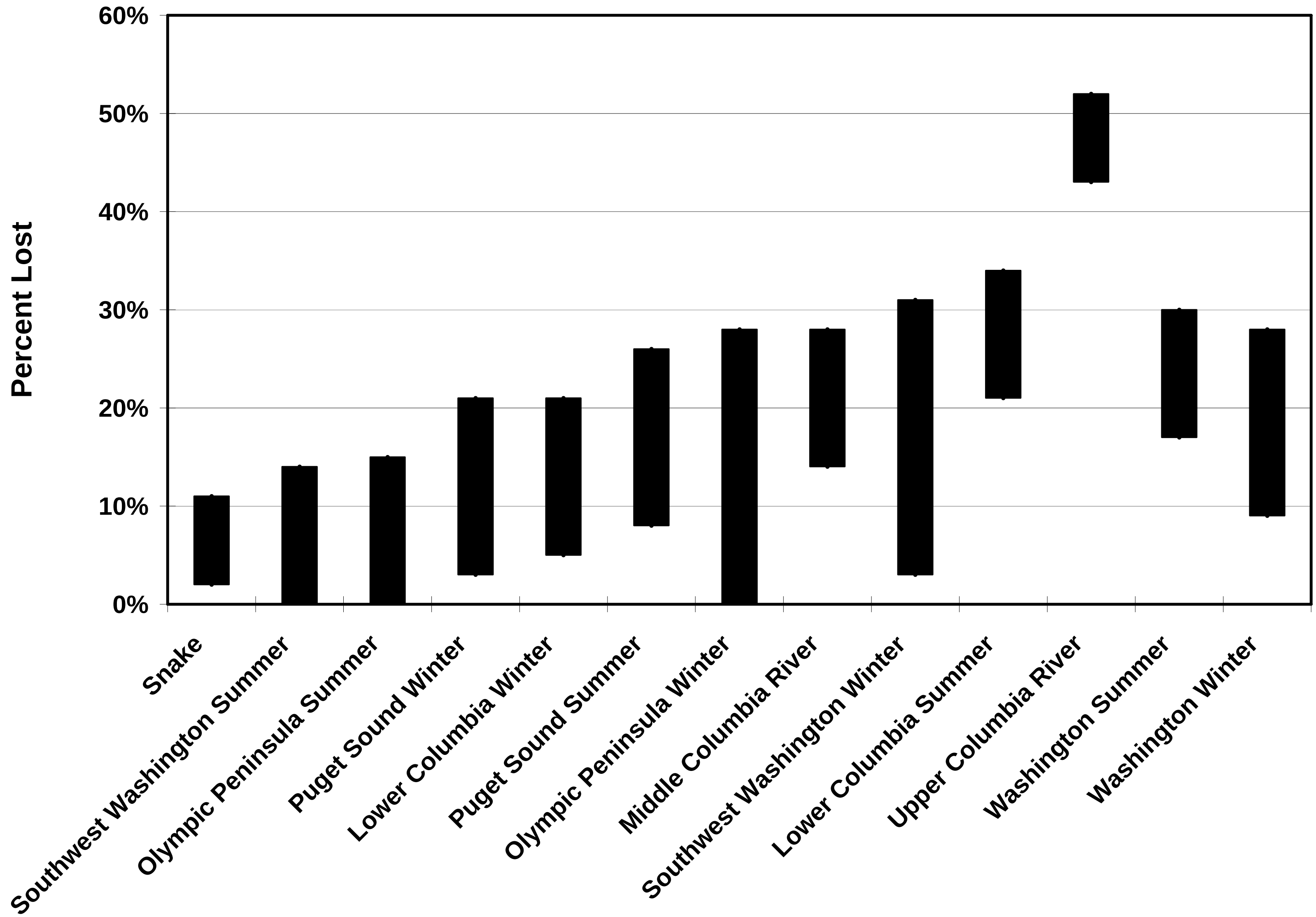

Figure 6-13. Percent reduction in the spatial extent of steelhead in each region in Washington.

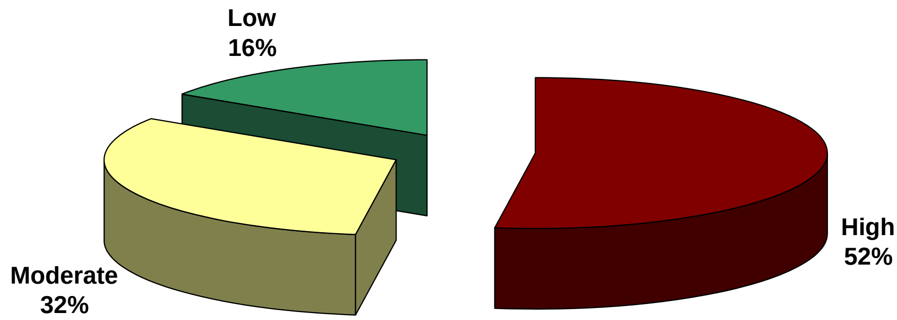

Figure 6-14. Percentage of populations with a High loss of spatial structure. Note that the index was not available for all populations in Washington.

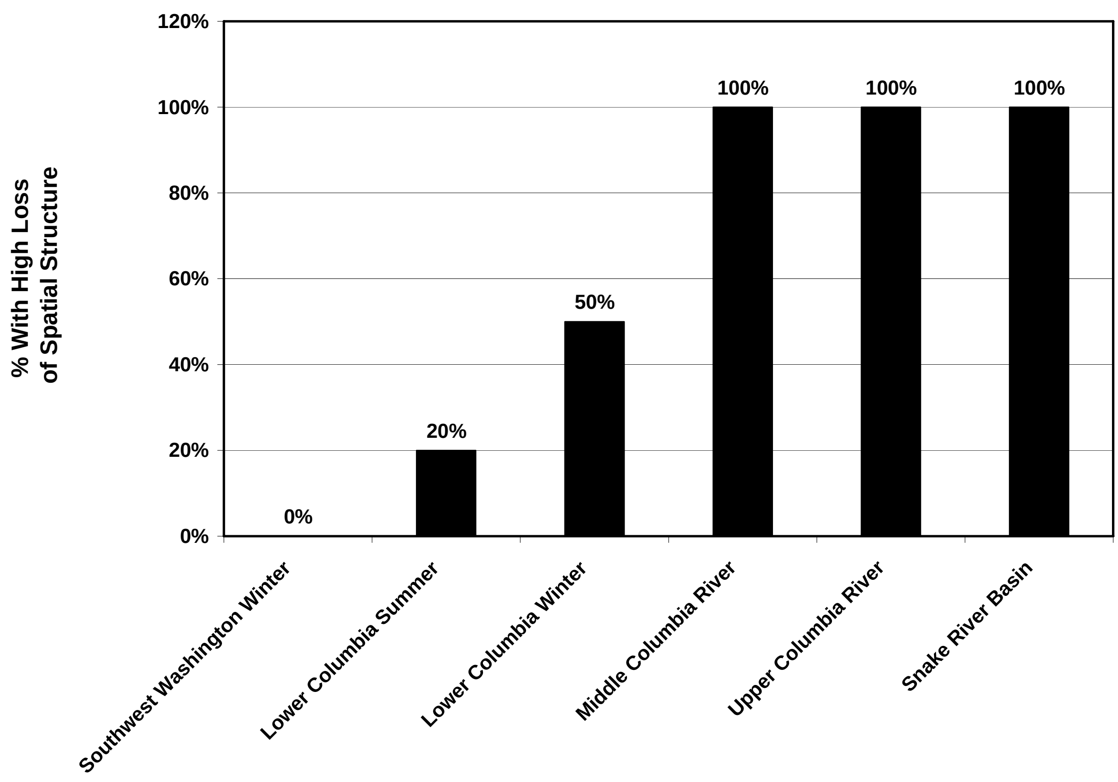

Figure 6-15. Reduction in the spatial structure of steelhead populations in Washington for which the index was computed.

A significant shortcoming exists in our ability to assess changes in the diversity of steelhead populations. Diversity was assessed for only 11% of the populations, typically in locations where research is evaluating the effects of artificial production programs (Yakima-Klickitat Fisheries Project, Snake River Laboratory). Our inability to evaluate changes in diversity is of particular concern given the importance of maintaining within-population diversity, the potential effects of artificial production, harvest, and habitat modifications on diversity, and the reductions in diversity noted in some populations. For populations for which diversity was assessed, 73% of the populations had a High loss of diversity, 20% had a Moderate loss of diversity, and 7% had a Low loss of diversity (Fig. 6-16). We suspect that a more exhaustive search will yield additional diversity data, but this only underscores the need for enhanced data collection, consistent reporting, and improved analyses.

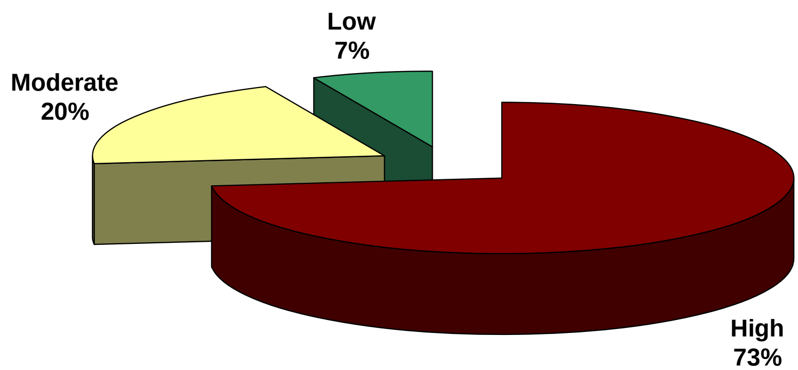

Figure 6-16. Percentage of steelhead populations in Washington that had a Low, Moderate, or High reduction in diversity. Note that the percentage is only for the 15 populations for which the change in diversity was not Unknown.

6.5 Findings and Recommendations

Finding 6-1. A substantial loss of spatial structure and diversity of steelhead populations has occurred in some regions. An estimated 9%-27% of historical winter steelhead habitat and 17%-30% of historical summer steelhead habitat in Washington is no longer accessible or utilized by steelhead. The largest reduction in utilization was in the Upper Columbia region, where an estimated 43%-52% of the historical habitat was no longer used by steelhead. The loss in spatial connectivity was categorized as “High” for 52% of the populations assessed statewide. For the 15 of 134 populations for which a diversity assessment could be completed, 73% had a “High” loss of diversity.

Recommendation 6-1. Pursue opportunities to preserve and restore population structure, spatial structure, and within-population diversity through careful review of harvest, hatchery, and habitat management and implementation of improved strategies.

Finding 6-2. Increased emphasis on monitoring the diversity of *O. mykiss* **populations is needed.** The assessment programs of WDFW, like many other resource management agencies, have traditionally focused on evaluating and monitoring abundance. However, fishery management is rapidly evolving with increased recognition of the importance of diversity in maintaining viable, productive populations. Unlike spawner abundance data, no consistent metrics, protocols, or structure for reporting and analysis of diversity currently exists. The lack of a monitoring program is of special concern for steelhead because of the wide range of life histories expressed by this species, the potential effects of artificial production, fishery harvest, and habitat modifications on diversity, and the reductions in diversity noted in some populations.

Recommendation 6-2. Design and initiate a program to monitor the genotypic and phenotypic characteristics of steelhead populations and a management structure for analysis and reporting. Expanding the scope of the Salmonid Stock Inventory (SaSI) to include data pertaining to diversity and spatial structure as well as spawner abundance data would promote concurrent reporting of all four of the viable salmonid population (VSP) characteristics.

Finding 6-3. A geographic information system (GIS) provides a powerful, cost-effective tool to analyze and present spatial data. Mapping the characteristics of habitat and distribution of redds now and in the future will be invaluable as we begin to assess the effectiveness of improved management strategies and recovery actions.

Recommendation 6-3. Enhance GIS capabilities by creating spatial data layers that identify barriers to fish passage, by incorporating additional variables into the model developed in this paper for predicting fish distribution, and by annually mapping the distribution of redds.

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Appendix 6-A. Methods for GIS Distribution Analysis

Current Distribution

Information on the distribution of summer and winter steelhead was collected during a two-year series of workshops conducted with fish biologists from WDFW, the tribes, and other federal, state, and local agencies. Based upon their experience in each watershed, the biologists reviewed and updated information from two sources: 1) the Limiting Factors Analysis conducted by the Washington Conservation Commission (Smith 2005); and 2) the 1:100,000 scale fish distribution database completed by WDFW in 1998. The biologists were asked to categorize fish distribution and usage according to the following criteria:

> Documented Presence. Stream segments for which steelhead presence is documented in published reports, survey notes, or first-hand sightings. This designation is applied to all stream segments downstream of a documented presence unless otherwise indicated by a formal review group.
>
> Documented Presence-Transported. Stream segments that meet the criteria for "Documented Presence" but for which steelhead presence is maintained by an ongoing fish passage operation (e.g., trap-and-haul) around a manmade barrier.
>
> Documented Presence-Artificial. Stream segments that meet the criteria for "Documented Presence" but which did not historically support steelhead because of the presence of a natural barrier. Current steelhead presence is the result of the removal of a natural barrier through the construction of a fishway, removal of an obstruction, or other factors.
>
> Documented Presence-Historic. Stream segments that formerly meet the criteria for "Documented Presence" based on documentation more than 20 years old at the time of mapping.
>
> Presumed Presence. Stream segments that lack documentation of steelhead use but where, based on the available data and best biological judgment, fish are *presumed* to occur. This presumption is based on the absence of natural or artificial barriers, a stream gradient $\leq$ 9% for winter steelhead and $\leq$ 12% for summer steelhead, and the presence of suitable habitat. In determining the suitability of habitat, the biologists considered habitat characteristics, life history requirements, proximity and connectivity to adjacent "Presence Documented" habitat sections, or logical extrapolation of range from similar systems.

> Potential Presence. Stream segments that meet the basic criteria for "Presumed Presence" but which do not currently support steelhead because of the presence of an anthropogenic factor (artificial obstruction or degraded habitat quality) which has a moderate to high potential to be eliminated. "Potential Presence" is not equivalent to the distribution of steelhead prior to European settlement for two reason: 1) it does not include habitat where anthropogenic factors limiting the distribution of steelhead have a low likelihood of being addressed (i.e., it is unlikely that passage above Grand Coulee Dam will be provided in the foreseeable future); or 2) it does not include habitat that biologists were not confident was suitable for use by steelhead.

We subsequently refined the "Presumed Presence" category to identify those areas where the presence of steelhead had historically been blocked by a natural barrier.

> Presumed Presence-Artificial. Stream segments that meet the criteria for "Presumed Presence" but which did not historically support steelhead because of the presence of a natural barrier. Current steelhead presence is the result of the removal of a natural barrier through the construction of a fishway, removal of an obstruction, or other factors.

The origin of steelhead using the stream segment was determined based on the *Salmonid and Steelhead Inventory 2002* (SaSI). Steelhead that are "NonNative" in origin (artificially introduced through hatchery programs) were not included in the maps or presence mileage tables but are discussed in the regional results section. The SaSI assessment of stock origin is available through the WDFW agency web page at http://wdfw.wa.gov/fish/sasi/ or through *http://wdfw.wa.gov/mapping/salmonscape/.*

The distribution information was linked to a 1:24,000 scale hydro-layer and integrated into the WDFW Washington Lakes and Rivers Information System (WLRIS) as a spatial (GIS) dataset. The "Current" distribution of steelhead was defined as:

Current =(Presence Documented) + (Presence Documented Transported) + (Presence Presumed)

Although only information on the "Current" distribution is provided in this report, more detailed maps for individual watersheds and a finer resolution of distribution categories are available through WDFW's SalmonScape web site at *http://wdfw.wa.gov/mapping/salmonscape/.*

The "Range Extension" of steelhead was defined as:

Range Extension = (Presence Documented Artificial) + (Presence Presumed Artificial)

Pre-Settlement Distribution

Information on the distribution of summer and winter steelhead prior to European settlement (referred to as the "Pre-Settlement" distribution) is limited. During the mapping workshops with biologists, we solicited expert opinion on what the distribution of steelhead would have been in the absence of artificial obstructions or habitat degradation ("Potential Presence"). Not surprisingly, the biologists were often unwilling to include parts of the watershed with which they were not personally familiar. The likely result was that the "Potential Presence" distribution defines a lower limit for the distribution of steelhead prior to European settlement.

We developed an alternative approach to explore this concern and define an upper limit to the distribution of steelhead prior to European settlement. The two-step methodology built on the information collected on the current distribution of steelhead and the spatial modeling capabilities provided by a Geographic Information System (GIS):

Step 1. Develop a GIS model driven by gradient and current distribution to predict historical the distribution of steelhead.

Step 2. Refine the model predictions through a review process with biologists familiar with the ecological and geomorphic characteristics of each watershed.

GIS analysis of the "Pre-Settlement" distribution was conducted only in rivers and streams where steelhead distribution has previously been defined as "Current", "Potential Presence", or "Documented Presence-Historic". The analysis identified stream segments below natural barriers where the gradient did not preclude passage by steelhead. The gradient criteria used for the analysis were ≤ 9% for winter steelhead and ≤ 12% for summer steelhead (SSHEAR 2000) over a contiguous 300 feet stream segment. The initial prediction of the "Pre-Settlement" distribution was defined as:

Lower Limit Pre-Settlement = "Current" + "Presence Potential"
Upper Limit Pre-Settlement = "Current" + "Presence Potential" + GIS Analysis

Maps created from the preliminary analysis were provided to biologists familiar with each watershed for review and refinement. The biologists used their knowledge of watershed characteristics such as riparian conditions, seasonal stream flow, and geomorphology to further constrain the upstream extent of the steelhead distribution. The spatial database was then rebuilt and used to predict the "Upper Limit Pre-

Settlement” distribution of steelhead with the exception of the area above Chief Joseph Dam.

The “Pre-Settlement” distribution of summer steelhead above Chief Joseph Dam was defined based on a 250K scale map from the Dec 1999 draft publication: *Conservation of Columbia Basin Fish: Building a Conceptual Recovery Plan Draft December1999* prepared by The Federal Caucus *www.bpa.gov/federalcaucus*. Refinements to the Upper Columbia Basin distribution will occur in the immediate future when additional information is received by WDFW.

A range contraction for steelhead was defined as:

Lower Limit Range Contraction = (Lower Limit Pre-Settlement) – (Current + Range Extension)
Upper Limit Range Contraction = (Upper Limit Pre-Settlement) – (Current + Range Extension)

Appendix 6-B. Methods for GIS Distribution Analysis

The Benefit-Risk Assessment Procedure (WDFW 2001) was used to identify the potential risk of effective size depression associated with artificial production programs. The table below summarizes the risk associated with different percentages of reduction in the effective size of the population at different levels of population abundance.

Categorization of Risk Associated with Effective Size Depression				
	Census Size of Composite Population			
		<1000/mean age	1000-1500/mean age	>1500/mean age
Percentage Effective Size Reduction	10	High	Moderate	Low
	20	High	Moderate	Low
	30	High	High	Moderate
	40	High	High	Moderate
	>40	High	High	High